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Cover illustration: Thin sections of several different habits of barite. Photographs: Jane Clarke.

Botryoidal barite Mag 538; ppl.	Acicular barite Mag 549; xpl.	Poikilotopic barite Mag 530; xpl.
Bladed barite (white) Mag 580; ppl.	Botryoidal barite Mag 538; xpl	Spherulitic barite Mag 584; xpl.
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The Geoff Brown Memorial Lecture: Predicting the next Supereruption

Hazel Rymer, Volcano Dynamics Group, The Open University, Walton Hall, Milton Keynes, Bucks, MK7 6AA

Abstract

Geoff Brown was one of the pioneers in the development of the micro-gravity technique for monitoring and modelling active volcanoes. In the 10 years since his tragic death on Galeras volcano, while he was setting up a new micro-gravity survey, the science has moved on and it is timely now to review progress in this fast changing field.

The reasons for studying volcanoes range from curiosity driven research to an urgent need for hazard mitigation by civil defence authorities. The hazard that a particular volcano poses will vary with time as the life cycle of a volcano dictates that activity will generally evolve from effusive to explosive. The risk to humans associated with the various hazards through time (lava flows, explosive eruptions, ash and gas etc.) depends on the level of urbanisation in the vicinity.

Ultimately the goal is to be able to predict eruptions accurately and in a timely way and in order to achieve that goal, it is necessary to develop a deeper understanding of how volcanoes work. Although the larger and (fortunately) rarer eruptions are those for which warning is the most essential, it is the smaller and more frequent eruptions that afford an opportunity to investigate the processes operating inside an active volcano. Thus academic geophysical monitoring is concentrated on active and persistently active volcanoes. The methods used depend on the processes to be investigated, but as with many other areas of research, a multidisciplinary approach is the most effective.

Introduction

The best and widest definition of a volcano was given by the OU's Peter Francis and is 'the surface manifestation of internal thermal processes by the emission of solid, liquid or gaseous products'. This is an especially good definition, because it covers not only the few hundred active volcanoes on Earth which erupt silicate magmas, but also the water volcanoes on the icy satellites, the sulphur volcanoes on Io and the nitrogen volcanoes on Triton. The vast majority of volcanoes in the Universe are well away from our Solar System, but would also be equally well covered by this definition.

The term 'super volcano' has crept into the popular literature but has no real meaning in scientific terms. The term 'super eruption' however, has been used in the scientific literature for the huge outpourings of lava or ash from volcanic centres seen in the geological record. These enormous eruptions occur at frequencies of hundreds of thousands of years and in volume exceed the equivalent of some 300km^3 of molten magma. In order to identify the processes associated with a super eruption, smaller, more frequent eruptions are studied. A range of geophysical techniques are used to monitor volcanoes in order to understand the processes involved and an integrated approach, involving more than one method is the most productive.

Geophysical monitoring

Of the 600 or so active volcanoes on earth, about 60 will erupt on any given day but the vast majority of these are not monitored.

Figure 1. Paper seismographs at the Costa Rican volcano observatory OVSICORI. Photo courtesy of Glyn Williams-Jones.

The few that are monitored at all may have just a single seismometer. The advantage of seismic monitoring over most other methods is that it is relatively cheap in terms of instrumentation. There is an immediate, often visible indication (Figure 1) of a change in activity. Detailed data analysis however is often not carried out and rolls of paper seismographs lie untouched on the shelves of some volcano observatories.

Seismic data used in conjunction with other data sets can be extremely powerful. For example, an increase in seismicity can alert geophysicists to an impending increase in activity. Other

Figure 2. GPS and micro-gravity measurements at Poas volcano, Costa Rica. The GPS receiver on the tripod is one of at least two that must be used in a network in order to obtain the high precisions required for monitoring. The gravity meters are read on exactly the same spot and at the same time as the GPS measurements are made in order for the ground deformation and gravity data to be comparable.

Table 1. Some commonly used techniques in volcano monitoring

Geophysical phenomenon	Instrumentation	Volcanic significance
Seismic disturbances	Seismometers	Tremors and vibrations may precede eruptions; changes in the level of seismicity may indicate magma / gas movements.
Ground deformation	GPS*, InSAR**, precision levelling	Vertical and horizontal movements may be a precursor to eruptive activity.
Temperature of gases and fluids	Thermal sensing cameras, thermocouples	Increases in temperature may reflect increase in activity; decrease may imply a blockage and therefore potential build-up of activity in future.
Ratios of gas species	FTIR***	Changes in ratio of say SO_2/CO_2 may indicate increasing magmatic component in gases.
SO_2 gas flux	COSPEC****, FLYSPEC	Increase in flux may indicate increase in activity; decrease may suggest blockage and a potential later build-up in activity.
Gravity changes	Gravity meters	Increase may indicate an intrusion of magma; a decrease may suggest a build up of gas-rich magma indicative of an explosive eruption.
Magnetic changes	Magnetometers	Decrease in total field strength may indicate the presence of hot magma, while an increase may reflect cooling of magma.

* Global Positioning System

** Interferometric Synthetic Aperture Radar

*** Fourier Transform Interferometry

**** Correlation Spectrometer

instrumentation placed at the onset of increased seismicity can be used to identify the causative processes more accurately and reliably than seismometers alone. There is a huge array of technologies available for volcano monitoring and in any particular situation some may be more appropriate than others. Some of the more common techniques are summarised in Table 1 and shown in Figures 1-5.

In the field, ground deformation monitoring can be carried out using the GPS (global positioning system) and the location of a pin on a rock can be determined to less than a centimetre horizontally and vertically using differential GPS. The equipment is relatively bulky (Figure 2), but as almost all activity is associated with ground deformation, this is a powerful method for monitoring activity.

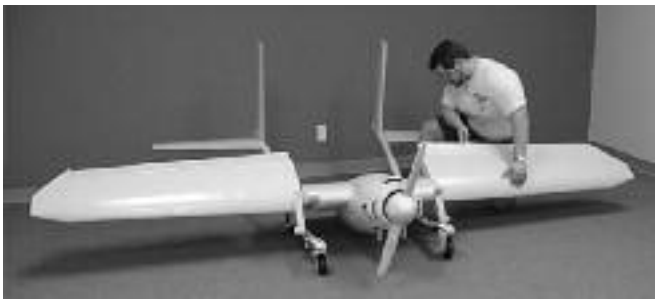

Figure 3. A remote controlled plane used for collecting geophysical data in remote and dangerous areas. This is not a cheap option for collecting data!

Temperatures of gases and fluids are monitored by thermal sensing cameras and these can be carried by small remote controlled planes (Figure 3) or hand held. These measurements are useful, but they are not always easy to obtain for practical reasons and they cannot contribute much to predictive models of volcanic activity as they provide information on gas or surface temperatures and not necessarily a measure of sub-surface processes going on in advance of surface activity.

Figure 4. FTIR measurements being made at Poas volcano. The large telescope is used to focus light from a hot source and the spectrometer on top analyses the light for wavelengths that have been absorbed by the gas.

Figure 5. FLYSPEC instruments are small and highly portable and can be carried easily beneath the gas plume in a car, a plane or even a backpack.

The ratios of particular gas species can be measured by Fourier Transform Interferometry (FTIR) and the flux of SO_2 by Correlation Spectrometers (COSPEC) and more recently by FLYSPEC. The FTIR method is cumbersome to use (Figure 4), and involves placing the instrument so that it can see a heat source (a large infrared light, a magma vent or similar) through the gas plume. In contrast the COSPEC and FLYSPEC are smaller spectrometers that are tracked beneath the gas plume, either by plane, by car or by backpack (Figure 5).

Minute changes in the acceleration due to gravity are measured using gravity meters (Figure 2). A series of points, usually marked by metal pins, are measured regularly and changes in gravity are recorded. Gravity varies according to the mass beneath the instrument and the distance from that mass. The most significant mass beneath the instrument is that of the whole Earth, and changes in the distance to the centre of the Earth are measured as ground deformation. Changes in gravity due to elevation changes can be easily corrected for and so any residual changes in gravity are due to sub-surface mass changes. Gravity change and height change

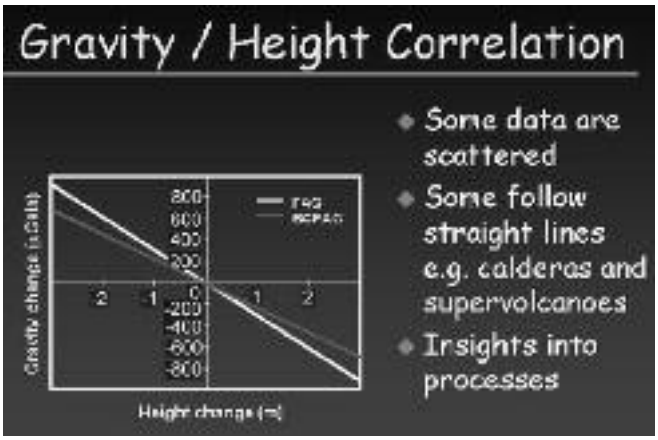
Gravity / Height Correlation
Some data are scattered
Some follow straight lines e.g. calderas and supervolcanoes
Irsights into processes
Gravity change (μGals)
Height change (m)

Figure 6. Deviations from the straight line relationships between gravity change and height change are interpreted in terms of sub-surface mass changes and can provide information on the process going on inside a volcano long before there is any evidence at the surface that an eruption is approaching.

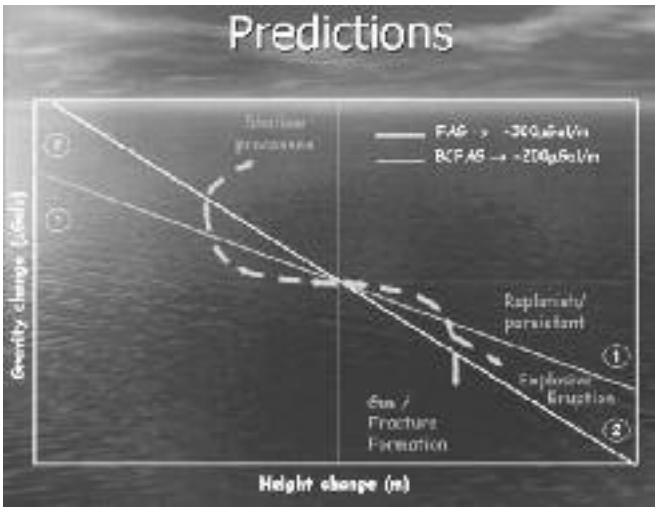

Figure 7. Predictions can be made by tracking gravity and height changes through time and seeing when the relation crosses into the region between the straight lines. At this point, the sub-surface processes may trigger an explosive eruption.

are related by a straight line; the gradient of the line depends on the model being used and ranges from the white line to the grey line (Figure 6). For measured gravity and height change data that do not fall onto either of these straight lines, a sub-surface mass or density change must be occurring. This is of interest in volcanology as the mass may be magma or magmatic gas. Predictions can be made by noting where the gravity and height change data fall onto the gravity/height graph and seeing how they vary with time (Figure 7). During uplift (right hand side of the figure), where gravity changes are small, the changes are likely to reflect replenishment of magma into the magma chamber. When the data fall in the region between the grey and white lines however, the processes inside the volcano are producing an overall mass increase and density decrease. This unstable situation is likely to involve the build up of gas pressure and possible explo-

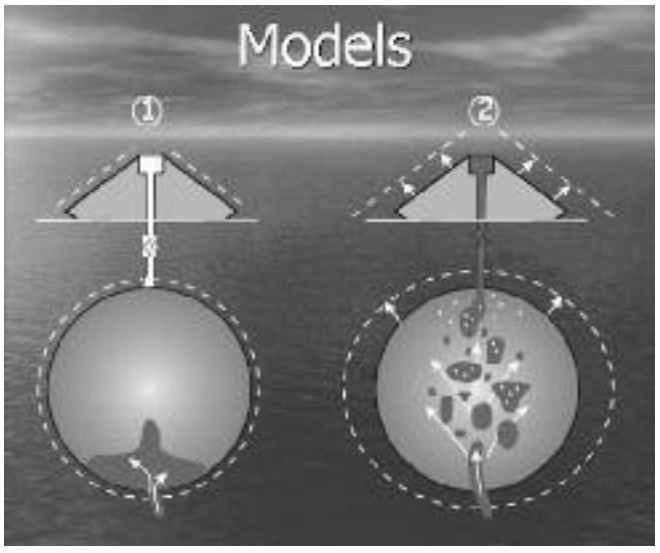

Figure 8. Two simple end member models for magma intrusion into a chamber. In model 1, magma intrudes gently and ponds or erupts quietly. In model 2, the intruding magma super-heats the magma in the chamber and the system becomes critical when vesiculation occurs and the magma may erupt explosively.

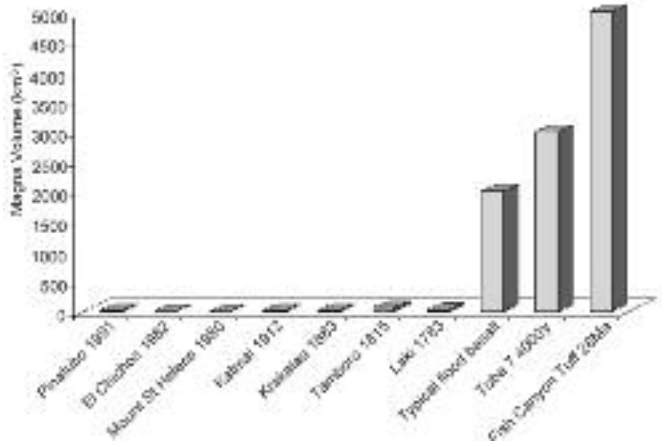

Figure 9. Relative sizes of classic volcanic eruptions.

sive eruption. A cartoon of the processes envisaged (Figure 8) illustrates the end member models in very simplistic terms. In model 1, magma intrudes a pre-existing chamber and either ponds in there or erupts quietly. In model 2, the intruding magma interacts with magma in the chamber and the system goes critical as vesiculation occurs and the density of the chamber decreases. Once the density has decreased below that of the surrounding country rock, the magma within the chamber may rise up rapidly and erupt explosively.

Caldera Unrest

The historic eruptions of Tambora in 1815 and more recently Pinatubo in 1991 give some indication of the effects of super eruptions (Table 2), although they were orders of magnitude smaller (Figure 9). By studying calderas in a state of unrest, we can observe some of the processes going on inside these volcanoes which may indicate what triggers a super eruption.

The Campi Flegrei caldera in Naples has been in a state of unrest for at least 2000 years. The centre of the caldera, near the town of Pozzuoli has been rising and falling by several metres throughout recorded history. The Roman temple of Serapeo is above sea level at present (Figure 10), and was uplifted by over a metre in a few months in the most recent crisis, but has spent much of its history below sea level.

Table 2. Comparison of large historic eruptions

Event	Equivalent volume of magma erupted, (km^3)	Peak eruption plume height, (km)	Peak eruption rate, (kg/s)
Toba 75,000 years ago	2800	> 30	?
Tambora, 1815	30-40	43	2800 million
Krakatau, 1883	12	25	50 million
Pinatubo, 1991	5	35	400 million
Vesuvius, AD 79	2.4	32	150 million
Mt St Helens, 1980	0.5	19	20 million

Figure 10. The Roman temple of Serapeo is above sea level, but is gradually sinking. It is in the centre of the Campi Flegrei caldera, the site of previous super eruptions and perhaps of a future super eruption.

The site is the subject of intense geophysical monitoring as huge populations live in and around the caldera. In the 1980s, the centre of the caldera rose by over 1m and there was concern that this could be the precursor to renewed activity. Combined gravity and ground deformation measurements (Figure 11) actually fell into the 'safe' region of Figure 7, although this predictive method had not been developed at the time. The period of uplift was characterised by relatively small gravity increases and so these are interpreted in terms of magma intrusion into the magma chamber, but no density decrease occurred within the chamber so significant vesiculation did not occur. The period of inflation was followed after a few months by deflation, which again was associated with a net gravity increase rather than decrease.

The next supereruption

Nobody knows where the next super eruption will be or when it will be. It is certain that there will be a super eruption and so it is important to look for the precursory signs that may well be present decades or more before the big event.

Figure 11.Gravity and height changes at Serapeo during the crisis of the 1980s and early 1990s. Rapid inflation was followed by more gradual deflation. The region is still in a state of gradual deflation at present.

Nisyros is located east of Santorini in the Mediterranean and an eruption could have serious consequences within the whole European Community. We have recently established a monitoring network on Nisyros to look for gravity and height changes. These data will complement gas and thermal data collected by colleagues from other universities in Greece.

Deformation data suggest that there is uplift on the island of Nisyros. It may be that the uplift is not related just to Nisyros island, but to the caldera of which Nisyros island is just the southern rim. Monitoring over the coming months and years will reveal whether there is a build up of magma beneath the caldera and whether it is vesiculating.

Conclusions

The last 10 years have brought huge advances into the field of volcano dynamics. Technology and communications have improved and become cheaper, so that enormous data sets can be handled electronically, where paper charts and hand calculations would have been used before.

In the field of gravity and ground deformation, gravity data from calderas in a state of unrest are now being collected and modelled. Before this, most data were restricted to persistently active volcanoes as the models for interpreting the changes associated with caldera unrest had not been developed.

The aim is to detect the precursory signals of an eruption in time to take precautionary action. In the case of a super eruption, the warning, should it be detected, is likely to be long, of the order of decades or more. The big question is whether governments and society in general will be able to think and act on such long timescales. Unless we are prepared for a super eruption, when it actually happens, the economic consequences and tens of millions of deaths will be devastating. In principle, just as individual countries have natural disaster preparation plans, the World Community needs preparation plans. If several billion people needed evacuation from most of Asia, and severe volcanic winter threatened agriculture throughout North America and Europe for several years in succession, could society cope? Questions like this will need to be addressed before the next super eruption.

Book review

The Cruise of the Betsey and Rambles of a Geologist, by Hugh Miller, 2003, Introduction and notes by Dr Michael A Taylor, NMS Publishing, 586pp (paperback) £20, ISBN 190166354X.

In 2002, the bicentenary of Hugh Miller's birth was commemorated with a flurry of activities and meetings throughout Scotland. Posthumously published in 1858 The Cruise of the Betsey and Rambles of a Geologist has been produced in a facsimile edition with financial assistance from his descendants and relatives and the National Museums of Scotland Charitable Trust. Dr Taylor, who is in charge of the Museum's fossil collections including that of Hugh Miller, has provided the introduction and various other notes. The introduction concludes with 12 pages of references and further reading. Throughout the text, indeed on almost every page, there are further footnotes explaining terms in Miller's text or adding biographical notes.

The Cruise of the Betsey, subtitled A Summer Ramble among the Fossiliferous Deposits of the Hebrides, is an account in 227 pages of a journey in the summers of 1844 and 1845 up the west coast around the Inner Hebrides. The Rambles of a Geologist describes his journeys in 1847 up the east coast. From Edinburgh he travels along the Moray coast, , throughout the Black Isle and Easter Ross and then "…took a coach at Invergordon for Wick early in the morning of Friday; and…alighted in Wick, at the inn door, a little after six o'clock in the evening." The journey to Wick is recounted in some 150 pages and the remaining c. 100 pages describe Miller's geological investigations in the Orkney Islands.

The facsimile edition ends with 36 pages of notes, a glossary, mainly of geological and palaeontological terms, and a comprehensive index.

I recall as a youth taking the mail ferry from Invergordon to Cromarty to visit Hugh Miller's cottage and wander along the shore towards the Sutor as Miller himself may have done. I may not have travelled the "ten thousand miles" in search of fossils but I certainly travelled many hundreds of miles by bicycle around Easter Ross searching out the sites of fossil fish in the middle Old Red Sandstone which were familiar to Miller himself.

From 'Asterolepis' to Zenaspis, from Ardnamurchan to Wick, the breadth of writing is as comprehensive as the range of fossils and places encountered. There is much to be learned in reading Miller's books; for example, the careful and detailed observation of the natural historian and the well written text of the journalist and editor. This is not just the journal of a geological tour of the Highlands and Islands, it is also an insightful commentary on the social conditions and culture of the people of the time.

In describing the island of Pabba, Miller writes, "Every rock is a tablet of hieroglyphics, with an ascertained alphabet; every rolled pebble a casket, with old pictorial records locked up within. Trap-dykes … stand up like fences over the sedimentary strata, or run out like moles far into the sea." And about a minister on the Isle of Eigg he writes, "In the course of time, through the natural gravitation operative in such cases, the poor incumbent became utterly scandalous, and was libelled for drunkenness before the General Assembly; but as the Island of Eigg lies remote from observation, evidence was difficult to procure; and, had not the infatuated man got senselessly drunk one evening, when in Edinburgh on trial, and staggered, of all places in the world, into the General Assembly, he would probably have died minister of Eigg." These quotations give a flavour of Miller's style.

Miller travelled around in coarse tweeds more like a lowland shepherd than an educated journalist; he did not use his reputation to gain comfortable lodgings on his travels unlike his fellow Black Isle geologist Roderick Murchison, only ten years his senior, who was ambitious and egotistical.

Hugh Miller was an English speaker: "John had not very much English, and I had no Gaelic; but we contrived to understand one another wonderfully well; and ere evening I had taught him to be quite as expert in hunting dead crocodiles as myself." Cromarty was not one of the small number of Gaelic-speaking fishing villages on the east coast such as Balintore, Embo and Helmsdale. "It was my misfortune to miss being born to this ancient language, by barely a mile of ferry." However, he did have Gaelic-speaking cousins, one of whom was a quarryman and this may have been Miller's inspiration to start work in a quarry before becoming a stonemason.

The original 486 pages of Miller's text is supplemented by a further 100 pages comprising by a foreword by Professor T.C. Smout, Historiographer Royal in Scotland, and the various sections by Dr Taylor, namely, the introduction, maps, notes about following in Miller's footsteps, including links to the world-wide web, references, notes about the geological framework now as compared to Miller's time, a comprehensive glossary, further notes in addition to the numerous footnotes, and an extensive index.

Hugh Miller is passionate about the geology of northern Scotland and he conveys this well in his writing. This is a marvellous book to read from cover to cover or, equally, to dip into at random for some delightful bedtime distractions.

Iain Allison, Glasgow University

Demystifying the Wealden of the Weald (Lower Cretaceous, south-east England)

Jonathan Radley

Abstract

The currently accepted model for the Wealden strata of the Weald (Hastings Beds and Weald Clay groups, Lower Cretaceous, southeast England) is outlined with reference to geological Sites of Special Scientific Interest. The Hastings Beds Group (Berriasian-Valanginian) includes several arenaceous formations that demonstrate alluvial fan construction in the Weald Sub-basin due to uplift of a London massif to the north, and to a lesser degree a southern, Armorican massif. The intercalated argillaceous formations indicate lacustrine/lagoonal transgression following massif downfaulting and provide palaeontological evidence for weak marine influence, probably from a Boreal seaway to the northwest. The overlying Weald Clay Group (Hauterivian-Aptian) attests to a deeply eroded, London massif prior to marine transgression in early Aptian times. The predominantly argillaceous facies again demonstrate a mosaic of lacustrine and brackish lagoonal environments. Seawater influxes are of Boreal and possibly Tethyan provenance. Thin sandstone members within the Weald Clay are probably the fringes of alluvial fans built out from a periodically uplifted Cornubian massif to the west. The Wealden biota includes terrestrial and aquatic reptiles, insects, molluscs and many plants. Palaeontological, sedimentological and geochemical evidence indicates a warm to hot, periodically wet Wealden climate, probably of Mediterranean aspect.

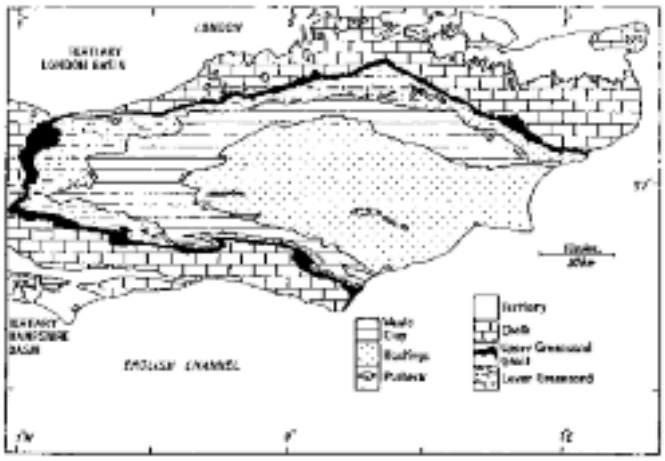

Figure 1. Map showing location of the Weald, southeast England. Adapted from Figure 4 in Ruffell A H, Ross A & Taylor K, 1996, *Early Cretaceous Environments of the Weald*. Geologists' Association Guide No. 55. Geologists' Association, London.

Introduction

The Weald district of southeast England includes parts of the counties of Kent, East and West Sussex, Surrey and Hampshire (Figure 1) and roughly coincides with the largely onshore post-Variscan Weald Sub-basin of the southern English Weald-Wessex Basin complex. Following Tertiary (Alpine) tectonic inversion, the Weald now encompasses an east-west trending anticlinorium of Lower Cretaceous strata (Gallois & Edmunds 1965, Chadwick 1986, Hawkes *et al*. 1998; Figure 1). This is the type area for the non-marine Barremian up to Aptian Wealden strata of northwest Europe (Allen & Wimbledon 1991). The core is the High Weald.

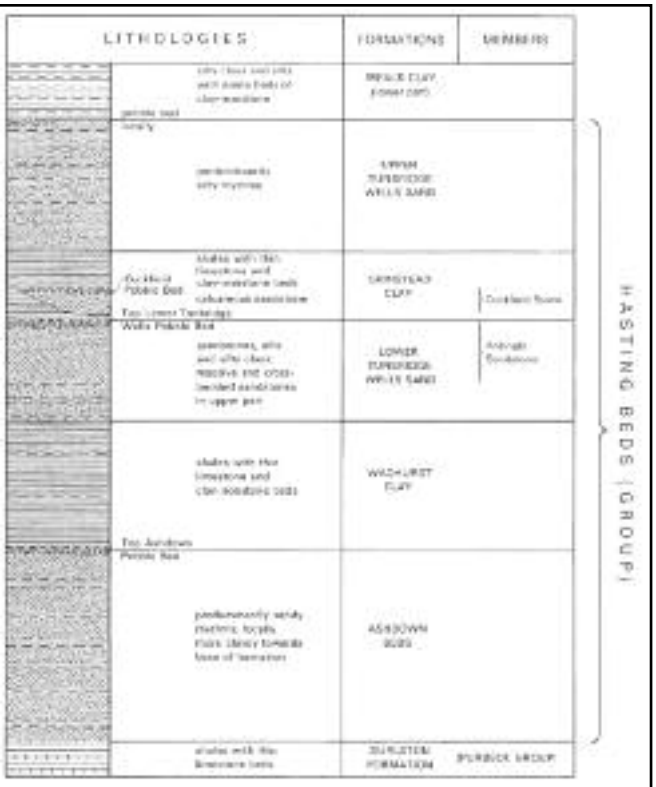

Figure 2. Outline lithostratigraphy of the Hastings Beds Group in the western Weald. IPR/40-12C British Geological Survey. © NERC. All rights reserved. From Gallois & Worssam (1993).

This picturesque terrain has been designated as an Area of Outstanding Natural Beauty (Countryside Commission 1994). It locally reaches 200m above sea level and is floored principally by the lower Wealden Hastings Beds Group (Figures 2 & 3), made up of mudstones and sandstones (Berriasian-Valanginian; possibly around 500m thick in the central Weald; Ross, in Rasnitsyn *et al.* 1998). Bordering the High Weald, the Low Weald is largely underlain by the upper Wealden Weald Clay Group (Hauterivian-Aptian; up to approximately 700m thick; Ross, in Rasnitsyn *et al*. 1998; Figures 3 & 4), fringed by escarpments of the overlying marine Lower Greensand. The Weald is bordered by the Upper Cretaceous Chalk hills of the North and South Downs.

During the early nineteenth century, geologists started to investigate the many small stone, sand and clay pits in the Weald. They encountered an array of strange fossils, not the familiar marine invertebrates of the Greensand and Chalk, but unusual plants and bones including the remains of the first-described dinosaurs. Since then, further investigations have led to good general knowledge of Wealden stratigraphy and palaeoenvironments. Many parts of the Wealden succession are still exposed in working brickpits, disused quarries, road cuttings, natural crags, stream outcrops and coastal sections.

The term 'Wealden' appears to have been first applied to the non-marine Lower Cretaceous strata by Peter Martin, a Sussex doctor in 1828. Subdivision into a lower Hastings Beds succession and a higher, Weald Clay division was established by eminent geolo-

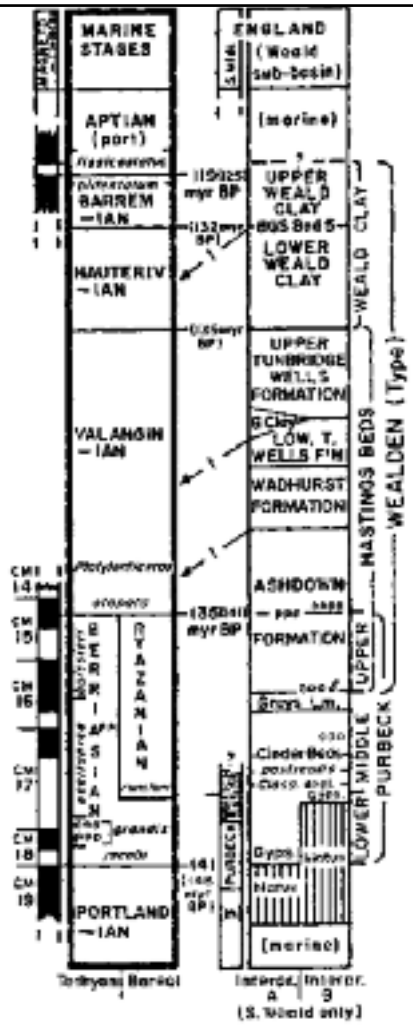

Figure 3. Wealden chronostratigraphy in the Weald Sub-basin. Reprinted from *Cretaceous Research*, vol. 12, Allen, P. & Wimbledon, W.A., Correlation of NW European Purbeck-Wealden (nonmarine Lower Cretaceous) as seen from the English type-areas, 511-526, Copyright (1991), with permission from Elsevier. Note that 'BGS Bed 5' [Weald Clay] should read 'BGS Bed 3a'.

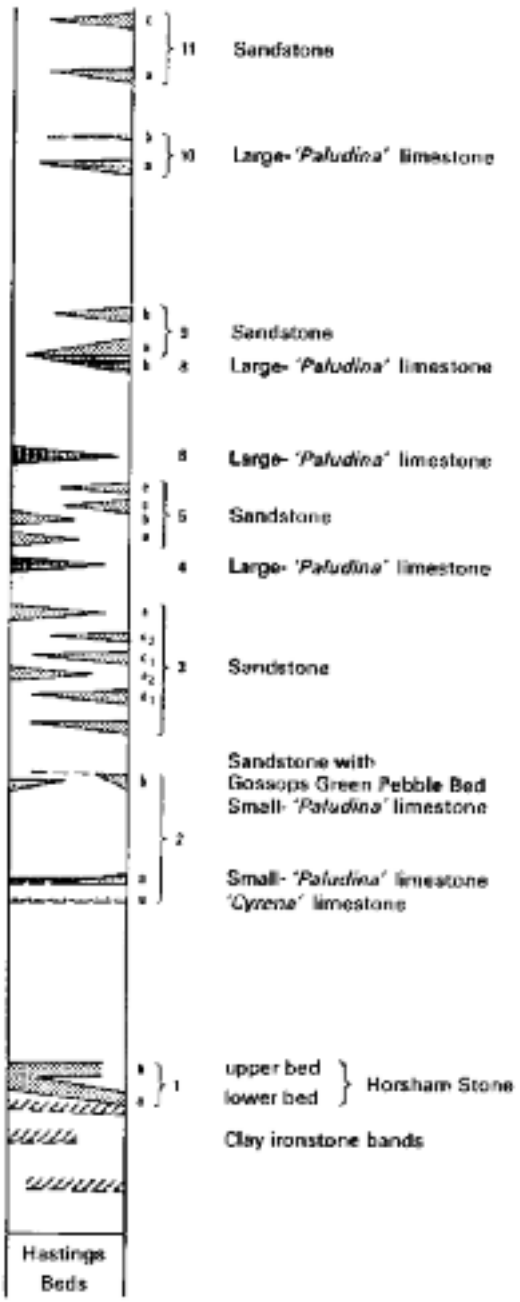

Figure 4. Generalised vertical section of the Weald Clay Group in the western Weald. IPR/40-12C British Geological Survey. © NERC. All rights reserved. From Gallois & Worssam (1993).

gists of the day, including Gideon Mantell, William Fitton and Roderick Murchison. The first comprehensive geological survey of the Weald commenced in the 1850's. This culminated with the publication of William Topley's memoir 'The Geology of the Weald' in 1875. Established in 1922, the Geologists' Association's Weald Research Committee published a wealth of new data over the following thirty years. Renewed field and subsurface investigations by the British Geological Survey have resulted in a range of modern maps, explanatory memoirs and related scientific papers, covering the Wealden outcrop.

Our modern understanding of Wealden environments stems largely from the researches of Professor P. Allen (The University of Reading), spanning more than sixty years. A comprehensive review of the Wealden flora and fauna is beyond the scope of this article. Reference to the most important palaeontological works, and those relating to stratigraphy and sedimentology can be found in Geological Survey memoirs for the Weald (e.g. Lake & Shephard-Thorn 1987; Gallois & Worssam 1993), the Geologists' Association's field guide to 'Early Cretaceous Environments of the Weald' (Ruffell *et al.* 1996), and Professor Allen's many papers (listed by Batten 1996). During 1995-1998 the specialist journal 'Cretaceous Research' included three issues featuring Wealden studies in honour of Professor Allen's achievements (vols 16 part 6, 17 part 1 and 19 parts 3-4).

Stratigraphy

Correlations of the Wealden strata with accurately dated marine successions (Figure 3) have relied largely upon microfossils (chiefly spores, pollen, microplankton, charophytes and ostracods) and integrated palaeontological and sedimentological studies (Allen & Wimbledon 1991 and references therein). The stratigraphic terminology used here is based on that currently adopted by the British Geological Survey (e.g. Gallois & Worssam 1993). Forming the lower part of the Wealden succession, the Hastings

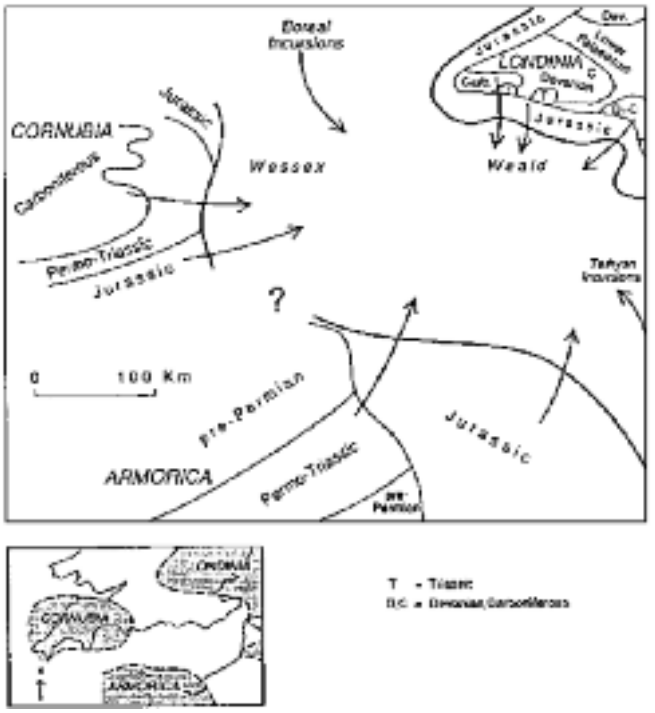

Figure 5. Generalised Wealden (late Barremian-early Aptian) palaeogeography and massif palaeogeology. Reproduced from Batten (1991) by permission of the Geological Society Publishing House.

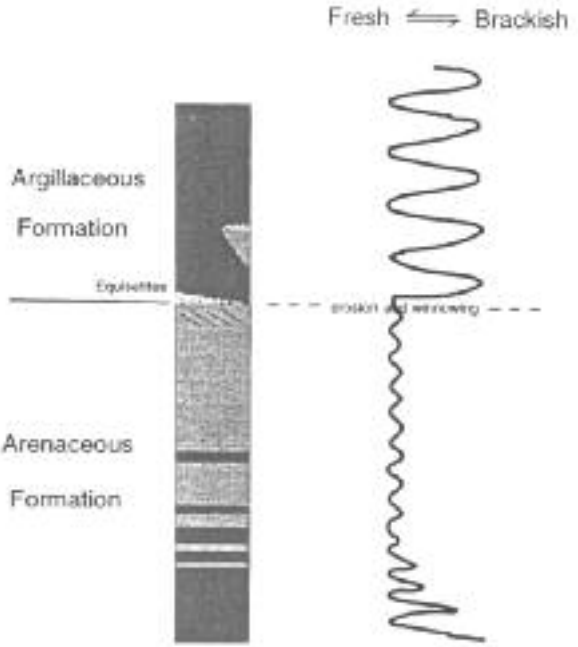

Figure 6. Schematic Hastings Beds megacycle (adapted from Allen 1959). Dark tone = mudstone; light tone = sandstone. Reprinted from Ruffell A H, Ross A & Taylor K, 1996, *Early Cretaceous Environments of the Weald*. Geologists' Association Guide No. 55. Geologists' Association, London.

Beds Group is subdivided into formations and members (Figure 2), and follows traditionally recognized units. The Survey have numbered the generally thin but mappable sandstone and limestone units of the overlying Weald Clay Group (Figure 4), following the scheme introduced by Topley (1875).

Structural and palaeoenvironmental setting

The northern margin of the Weald Sub-basin is marked by east-west and northwest-southeast trending faults (Chadwick 1986, Hawkes *et al*. 1998). These lie close to the southern edge of the now buried 'stump' of the London massif, often termed 'Londinia' (Figure 5). Some of the faults appear to be associated with lateral thickness changes within the Wealden succession (Gallois & Worssam 1993), suggesting that they were active during the Lower Cretaceous. The southern boundary of the Sub-basin is marked by the northern edge of the Portsdown-South Downs High (Hawkes *et al*. 1998). To the southwest of the Weald, the Wessex (or 'Channel') Sub-basin extends southwards beneath the English Channel, offshore of the Isle of Wight-south Dorset area (Allen 1981, Hawkes *et al*. 1998; Figure 5).

At the dawn of the Cretaceous, approximately 135 million years ago, the Weald Sub-basin was approximately 20° south of its present latitude (Allen 1998). Deposition in the southern English area had become largely confined to the Weald and Wessex Sub-basins (Figure 5). This was probably due to a combination of eustatic sea-level fall and normal faulting linked with North Atlantic rifting (Allen 1981, Chadwick 1986). At that time muddy lacustrine-lagoonal environments of 'Purbeck' type dominated the Weald (Howitt 1964, Allen 1975).

Towards the end of the Berriasian Stage the 'Purbeck' muds and shell banks were gradually replaced by arenaceous Wealden sediments (Allen 1975, Hancock & Rawson 1992). Sedimentological studies of these early Wealden strata (the Hastings Beds Group) indicate complexes of alluvial fans building out southwards from the rejuvenated London massif and to a lesser extent, northeastwards from a southern massif ('Armorica') (Allen 1975, 1981, Sladen & Batten 1984, Hancock & Rawson 1992). Repetitive Londinian upfaulting during the Valanginian Stage is recorded by three sandstone-dominated formations within the Hastings Beds Group (Ashdown Beds; Lower and Upper Tunbridge Wells Sand formations, Figures 2 & 3), each representing a major fan-building episode (Allen 1975, Ruffell *et al.* 1996). Petrographic studies of the sand and gravel indicate that, to the north of the Weald, the Londinian interior was predominantly an upland terrain of cherty Lower Carboniferous limestone overlying pebbly Devonian Old Red Sandstone (Allen 1967, 1981). This Upper Palaeozoic core appears to have been bordered by Upper Jurassic scarplands (Figure 5). Near the southeastern end of the Sub-basin, the outwash seems to have been derived in part from Precambrian-Lower Palaeozoic quartz-veined slates, phyllites and siltstones outcropping in the northeast Kent area and beyond (Allen 1967).

Mud-dominated formations within the Hastings Beds Group (the Wadhurst and Grinstead Clay formations, Figures 2 & 3) point to intervening phases of massif downfaulting, resulting in re-establishment of lacustrine and lagoonal facies in the sub-basin (see below). Allen defined the formation-scale sandstone-mudstone couplets that make up the Hastings Beds as 'megacyclothems' and later as 'megacycles' (Allen 1959, 1975). Where fully developed, each megacycle commences with largely argillaceous meander-plain and lake shoreline sediments that coarsen up into arenaceous braidplain facies truncated by a gravel-strewn erosion surface of lake shoreline origin. Above, the sequence is developed as an argillaceous lacustrine/lagoonal formation. This culminates

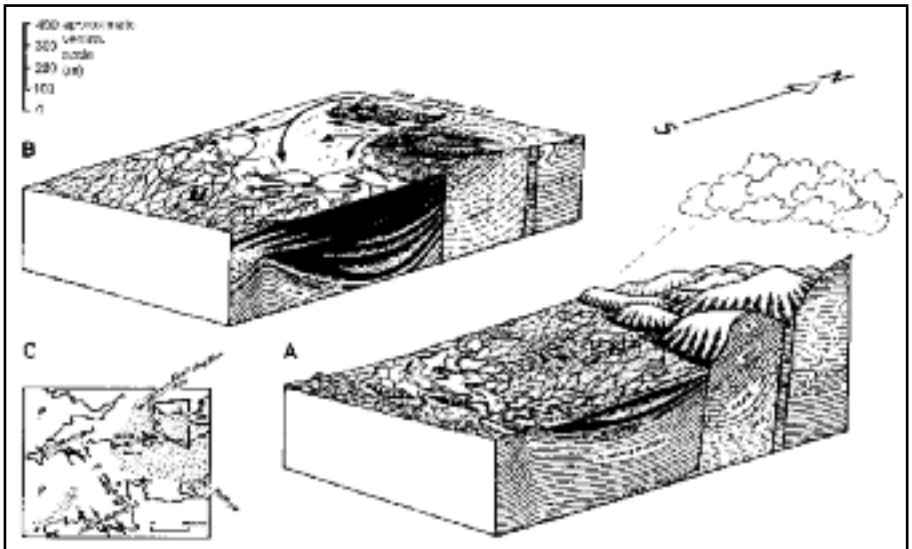

Figure. 7. Model for the Wealden of the Weald Sub-basin.

A. Arenaceous formations of the Hastings Beds Group. Uplift of London massif produces high relief and stream flow. Braided alluvial systems spread across muds from the north. Note the east-west trending Portsdown-South Downs High in the extreme south of the Sub-basin.

B. Argillaceous formations. Downfaulting and denudation of the London massif reduce relief and streamflow. Weald Sub-basin reverts to muddy freshwater-brackish lake-lagoon complex.

C. Regional setting. The smaller frame outlines the area covered by A and B above. Dotted area shows the approximate present extent of the Wealden. The fault symbols suggest the margins of active blocks.

Reproduced by permission of the Geologists' Association from *Proceedings of the Geologists' Association*, Allen P, Wealden of the Weald: a new model, 86, p.424, Fig. 8. © 1975 The Geologists' Association.

ultimately in distal alluvial and/or lake margin facies again and marks renewed massif uplift and the base of the next megacycle (Figures 6 & 7). Overlying the Hastings Beds, the Weald Clay Group's thin, characteristically tourmaline-rich sandstones were perhaps deposited along the distal fringes of alluvial fans built eastward from the Cornubian massif ('Cornubia') that occupied the general region of Devon, Cornwall and the Scilly Isles (Allen 1975, 1989; Figures 4 & 5). Like the Hastings Beds fans they are seen as resulting from periodic uplifts of the source area which increased the stream gradients and perhaps rainfall. Scarcity or lack of Londinian and Armorican detritus (Allen 1975) suggests that relief on the other massifs was now very low (Chadwick 1986, Hancock & Rawson 1992).

Wealden SSSIs and their interpretation

The Wealden reveals a number of broad stratigraphic patterns and cycles, reflecting palaeogeographic, tectonic and perhaps climatic controls on deposition. These are the keys to understanding the succession. As part of the Geological Conservation Review programme, English Nature, the Government's Nature Conservation Agency has established a network of more than 25 geological sites throughout the Weald that demonstrate the evolution and diversity of Wealden rock types, lithofacies and palaeoenvironments through time. These are afforded statutory protection through their Site of Special Scientific Interest (SSSI) status. The Wealden story is outlined here with special reference to these sites.

Ashdown Beds - Wadhurst Clay megacycle

Beneath the Wealden, the essentially lacustrine Upper Purbeck Beds (Berriasian in age) are exposed along the River Line, 4km northwest of Battle, East Sussex (River Line SSSI; TQ714190-719192, Howitt 1964). At the south-western end of the section the Upper Purbeck is dominated by beds of shale, shelly limestone and sandstone that yield abundant ostracods, fresh to brackish-water bivalves and gastropods. Overlying the Purbeck, the argillaceous and ultimately arenaceous Ashdown Beds Formation forms the lower part of the Ashdown-Wadhurst megacycle (Figure 6). The Ashdown Beds are developed throughout the Weald (maximum thickness around 200m) and signify the initial (late Berriasian) phase of Wealden fan construction. They are well exposed in sea cliffs and intertidal sections running for roughly 7km between Hastings and Pett Level (Hastings-Pett Level SSSI; TQ828093-888132; Lake & Shephard-Thorn 1987 and references therein). The lowest strata, seen near Fairlight, must lie shortly above the top of the Purbeck Formation. They are characterized by oxidized and colour-mottled mudstones with rootlet traces, mud-cracks, lenses of intraformational breccia, lignite fragments and nodular siderite. The beds are interpreted as floodplain alluvium comparable with that of some present-day subtropical wetlands. The mudstones are commonly rich in kaolinite (Sladen, in Lake & Shephard-Thorn 1987). This may have originated through acid leaching of soils on Londinia, suggesting a warm, humid Wealden climate (Allen 1998). The mudstones at Fairlight have yielded the well-known Fairlight flora. Water, heat and fire-related adaptations have been identified in some of the plants (Watson & Alvin 1996), strengthening Allen's concept of long dry periods punctuated by heavy rainfall (Allen 1998).

A general upward increase in sandstone bodies through the Ashdown Beds shows that the Fairlight wetlands were gradually succeeded by braidplain environments, as massif uplift continued (Allen 1975; Figures 6 & 7). Current structures within the Ashdown Beds along the Hastings coast show that the streams of sand were derived from the Kentish end of Londinia (Figure 5). East of Lee Ness Ledge (TQ867108), tridactyl dinosaur footcasts attributable to *Iguanodon* and carnivorous theropods are well preserved, especially on the base of the Lee Ness Sandstone near the bottom of the succession (Lake & Shephard-Thorn 1987, Woodhams & Hines 1989; Figure 8). Finger-sized burrows (*Beaconites*), penetrate parts of the sandstone. These typical Wealden trace fossils characterize fluvial and fluvially influenced marginal lake margin settings (Goldring & Pollard 1995; Figure 9). Cross-beds and channels of varying size are preserved in the higher Ashdown sandstones along the coast. They point to scours, river channels, inter-channel sandflats and possibly small fans invading shallow interchannel lakes (Allen 1975). Invertebrate fossils have been found including plants, molluscs and insects.

Figure 8. *Iguanodon* footcast preserved on the base of the Lee Ness Sandstone, Ashdown Beds Formation, Lee Ness Ledge, Fairlight, East Sussex. Footcast width: 40 cm. Photograph supplied by Ken Brooks (Hastings and District Geological Society).

In the High Weald, the sparsely pebbly Top Ashdown Sandstone Member locally caps the Ashdown Beds. Traces of stems and rootlets of the inferred clubmoss *Lycopodites hannahensis* Harris have been found within the sandstone in a sunken lane at Waldron, East Sussex (Waldron SSSI; TQ552187), 30km north-west of Hastings. Further variation is indicated by a roadside section 8km north-northwest of Waldron (Hadlow Down SSSI; TQ523259), where a possible point-bar suggests periodic re-establishment of meandering streams on the upper Ashdown floodplain (Allen 1981). Fossil charcoal in the sandstones at Hadlow Down and elsewhere probably resulted from wildfires in the sub-basin and/or on the nearby uplands. The Top Ashdown Sandstone is truncated by a widespread erosion surface that marks the top of the Ashdown Beds. This was a time of major environmental change (Figure 6).

Completing the megacycle, the overlying Wadhurst Clay Formation (up to about 80m thick) is also present throughout the Weald (Figures 2, 3 & 6). Allen's investigations of the basal passage beds (Allen 1975, 1989 and references therein) show that they mark the spread of a freshwater to slightly brackish lake or lakes into the Sub-basin (Figures 6 & 7). *Equisetites* ('horsetail') soil beds, suncracked surfaces and probable pond-dwelling, desiccation-resistant ostracods occur throughout the Wadhurst Clay (Allen 1989, Horne 1995), showing that the slightly deepening waters were always extremely shallow. This suggests Londinian downfaulting as the most likely mechanism for the abrupt change from alluvial to lake facies, rather than slow sea-level rise (Allen 1975, 1981; Figures 6 & 7). The passage beds begin with the Top Ashdown Pebble Bed, exposed at several SSSIs in the southeastern High Weald. On the Hastings coast it is represented by an impersistent seam of ferruginous sandstone, containing Londinian quartz, quartzite and chert pebbles. The sand fractions of the Top Ashdown Sandstone and overlying Pebble Bed include grains of high-grade metamorphic rocks and glauconite. The detritus was probably derived from Hercynian metamorphic and Upper

Figure 9. *Beaconites* burrows within the Clock House Sandstone (Lower Weald Clay, BGS Bed 3), Clockhouse Brickworks, near Capel, Surrey.

Jurassic sedimentary terrains, on Armorica and Londinia respectively (Allen 1948; Figure 5). The Pebble Bed is thought to represent relic braidplain debris, reworked along the spreading lake shoreline. Absence of calcareous pebbles hints at acid leaching conditions on the hinterland, supporting the clay mineral evidence from the underlying Ashdown Beds (Allen 1998). The top of the Pebble Bed is commonly symmetrically rippled, showing that the pebbly sand was reworked by widely oscillating currents in the lake shallows, possibly during periodic storms.

Above the Pebble Bed, the remaining passage beds are typified by the succession preserved in a 'sunken lane' section at Brede, East Sussex, 9km north of Hastings (Brede SSSI; TQ 832185). A thin layer of shaly mudstone with sandstone flute and gutter casts, vertebrate debris and shells encloses horsetail plants (*Equisetites*) in growth position. The vertical stems end abruptly beneath a thin layer with subaerial horsetail fragments. This is the Brede Soil Bed and such packages are recognizable at other horizons throughout the Weald. It clearly represents the remnants of a horsetail 'reed'-bed, rooted in up to about a metre of fresh-water (Allen 1989). The plants are seen as separating a nearshore, fluvially influenced area of an early Wadhurst lake margin from offshore muds. Silicified fragments of a large tree-fern (*Tempskya schimperi* Corda) are common amongst the beach pebbles along the Hastings-Pett Level coast and are thought to be derived largely or wholly from the lower Wadhurst beds. These are somewhat inaccessible, so whether they are 'growing' *in situ* there is uncertain.

The overlying Wadhurst mudstones are relatively poor in kaolinite, but rich in *Classopollis* (cheirolepidiacean conifer) pollen. Sladen & Batten (1984) took this clay mineral and palynological evidence to indicate a drier climate, perhaps due to lower massif relief. The typically grey lower Wadhurst mudstones are well exposed at Sharpthorne Brickworks near West Hoathly, West Sussex (West Hoathly (Sharpthorne) SSSI; TQ374328). Sideritic clay-ironstone in the Wadhurst Clay was largely responsible for the former Wealden iron industry. Clay-ironstone lenses within the Sharpthorne mudstones enclose storm-deposited concentrations of small bivalve shells (*Neomiodon*), pond-snails (*Viviparus*) and ostracods. *Neomiodon* shells from this site have been isotopically analysed and the results suggest a degree of brackishness (Allen *et al*. 1973). Siltstone and fine sandstone gutter- and scour-fills at Sharpthorne further indicate storm activity

Figure 10. Philpots Quarry, West Hoathly, West Sussex. Ardingly Sandstone Member of the Lower Tunbridge Wells Sand Formation, overlain by the Grinstead Clay Formation. The junction of the two units is marked by the Top Lower Tunbridge Wells Pebble Bed.

and/or enhanced fluvial runoff into the water-body. They also reveal beautifully preserved trace fossils, recording thriving communities of soft-bodied animals on and in the lakebed. Younger Wadhurst mudstones at Freshfield Lane Brickworks, near Horsted Keynes, West Sussex (Horsted Keynes SSSI; TQ381266) feature the High Brooms *Equisetites* Soil Bed (see below) and thin limestones largely composed of the pond-snail *Viviparus*.

Sandstone bodies, up to around 10m thick, are a conspicuous feature of the Wadhurst Clay Formation in the southeastern Weald (Allen 1975, Lake & Shephard-Thorn 1987). Where calcite-cemented, the sandstones have been termed 'Tilgate Stone' and were once an important source of stone for walls, paving and buildings. Field mapping has shown that the thicker sandstone units possess channel-like geometries up to several kilometres across. They appear to represent small fan-deltas, built out into the Wadhurst lakes principally from the eastern end of the down-faulted London massif (Figure 5; Allen 1975, 1989). Among the sandstones, the coarsening-upward Cliff End Sandstone Member cuts down almost to the base of the Wadhurst Clay along the Hastings–Pett Level coast. Its top is locally leached and penetrated by plant root traces, well seen in disused quarries above Covehurst Bay (Fairlight SSSI; TQ858115; 859119). These features suggest that, following abandonment, the Cliff End fan-delta became a well-drained vegetated elevation among the Wadhurst muds (Allen 1989). The succeeding mudstones near Pett Level enclose the pebbly Cliff End Bone Bed. This has yielded teeth of fish, crocodiles and primitive mammals. Inland, the Telham Bone Bed (Battle SSSI; TQ769142) has also yielded water-worn bones and teeth of dinosaurs and aquatic reptiles (Benton & Spencer 1995 and references therein).

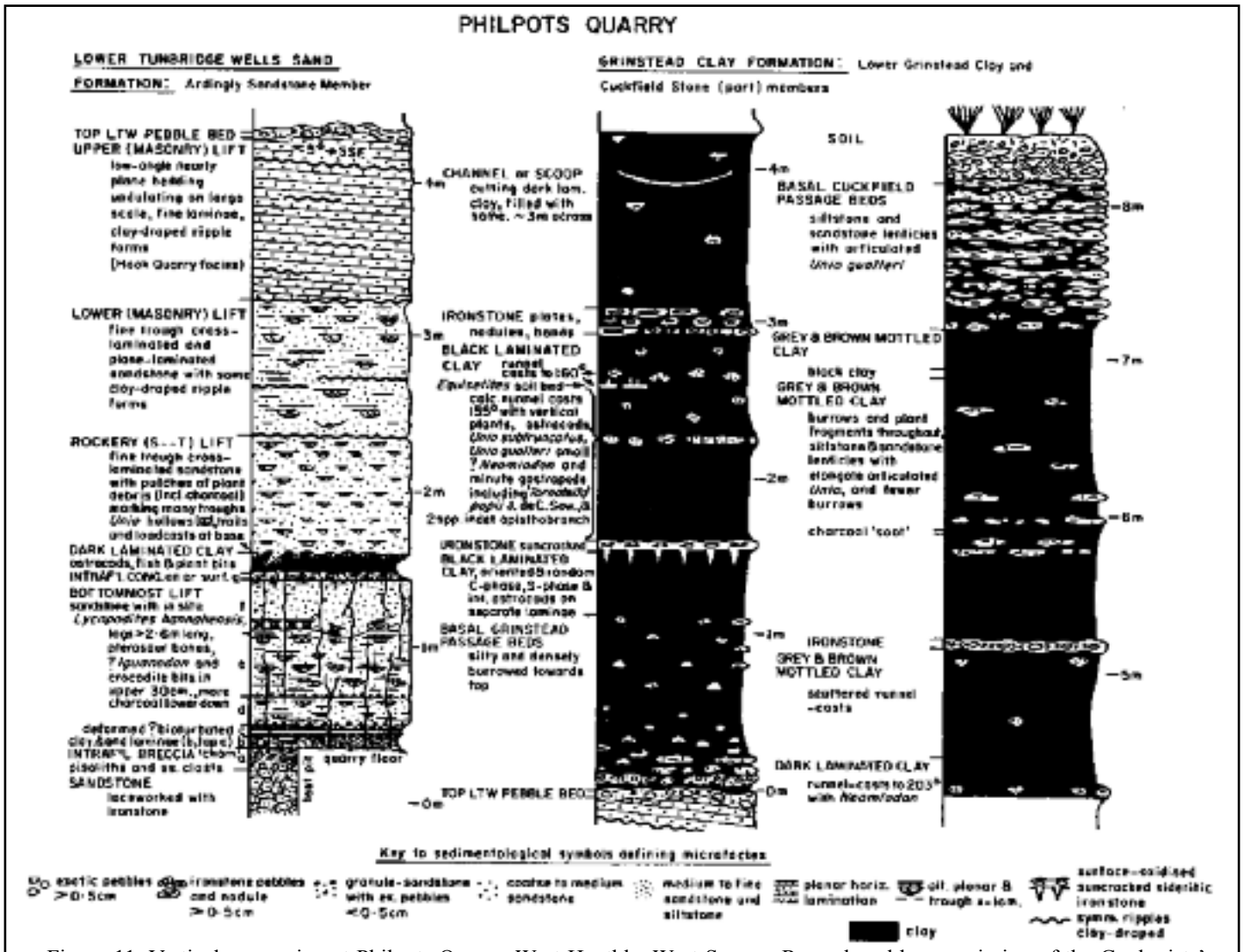

Figure 11. Vertical succession at Philpots Quarry, West Hoathly, West Sussex. Reproduced by permission of the Geologists' Association from *Proceedings of the Geologists' Association*, Allen P, Wealden research – ways ahead, 100, p.531, Fig. 2. © 1989 The Geologists' Association.

Figure 12. Stone Farm Rocks, near East Grinstead, West Sussex. Crags of Ardingly Sandstone (Lower Tunbridge Wells Sand Formation), approximately 6m high. Weir Wood Reservoir is visible in the background.

The Wadhurst Clay – Lower Tunbridge Wells Sand transition beds are preserved at Freshfield Lane Brickworks (Gallois & Worssam 1993). There, the High Brooms *Equisetites* Soil Bed (Allen 1975) provides evidence for a horsetail fence building out into shallow lake fresh-water, hinting at renewed massif uplift. Shortly above, colour-mottled mudstones are taken as evidence for subaerial exposure along the retreating lake margin. The detrital gradients and petrography of the overlying Lower Tunbridge Wells Sand (up to 40m thick) confirm a renewed Londinian influence from the rejuvenated massif (Allen 1975; Figure 7).

Lower Tunbridge Wells Sand - Grinstead Clay megacycle

The poorly exposed lower part of the Lower Tunbridge Wells Sand Formation is characterized by siltstones and fine-grained sandstones (Gallois & Worssam 1993). The higher part of the formation comprises the relatively massive Ardingly Sandstone Member (Figure 2), recording re-establishment of a braidplain (Figure 7). It is well exposed in disused stone pits and natural crags, as in the West Hoathly, Ardingly, East Grinstead and Tunbridge Wells areas. Roadside sections at Turners Hill, West Sussex (Turners Hill SSSI; TQ339354) expose thinly trough cross-bedded fine sandstones. A few kilometres to the southeast, Philpots Quarry, West Hoathly (West Hoathly (Philpots) SSSI; TQ 356323, Figure 10) now disused, was intensely researched by P. Allen over many years as quarrying progressed (Allen 1975, 1989 and references therein). The upper part of the Ardingly Sandstone there comprises several metre-thick beds of fine-grained, planar to trough cross-laminated sandstone (Figures 10 & 11). Partings between the beds reveal many interesting features including reworked soil debris of subtropical/tropical lateritic aspect, ostracods, conchostracans, fish remains and the 'resting' traces of pond mussels (Allen 1989, Taylor 1992, Ruffell *et al.* 1996). The sandstones themselves have yielded burnt wood fragments, fish skeletons and *Iguanodon* bones, and enclose stems of the possible clubmoss *Lycopodites* and scoop-like channel structures. The Philpots Quarry sandstones and those at the nearby Hook Quarry (West Hoathly (Hook) SSSI; TQ356323) form part of a patchwork of shallow channels, scours and small fans. Current directions confirm transport from the Londinian source to the north (Allen 1975).

Closer to the northern limit of its outcrop, the Ardingly Sandstone of Stone Farm Rocks (East Grinstead SSSI; TQ381347, Figure 12) and High Rocks (Tunbridge Wells SSSI; TQ558382-562384) comprises fine to coarse grained and pebbly sandstones displaying trough cross bedding, wavy bedding and soft sediment deformation. Regional current directions and interpretation of the pebble assemblages affirm that the two sites represent coalescing fans. Approximately 6km northeast of High Rocks, disused quarries at Pembury SSSI, Kent (TQ6141) expose cross-bedded sandstones, silts, mudstones and intraformational conglomerates. This development of the Ardingly Sandstone represents channels and scours of varying scale and perhaps just a few tens of kilometers south of Londinia (Allen 1962).

The Grinstead Clay Formation (up to around 30m thick) abruptly overlies the eroded top of the Ardingly Sandstone in the central and western Weald and strongly recalls the earlier Ashdown-Wadhurst junction (Figure 2). Thus, forming the lower part of the Lower Grinstead Clay Member, the basal Grinstead passage beds similarly commence with the widespread Top Lower Tunbridge Wells Pebble Bed, intensely studied at the Philpots and Hook quarries (Allen 1975, 1989 and references therein; Figure 11). There, the typically Londinian pebble suite is dominated by quartz, jasper and quartzite from Old Red Sandstone pebble beds, silicified Carboniferous Limestone, and phosphatised Upper Jurassic materials which include Kimmeridge Clay ammonite fragments (Allen 1960, 1961, 1967). Armorican detritus has not been identified. Once again, calcareous pebbles are absent and many of the cherts are partly decomposed. This implies a similar weathering regime on Londinia to that of Ashdown times. A significant kaolinite component amongst the underlying Ardingly Sandstone supports this notion (Sladen & Batten 1984). Like the Top Ashdown Pebble Bed the Top Lower Tunbridge Wells example is modelled as braidplain gravel reworked along a spreading lake shoreline.

At the Philpots Quarry, the remaining passage strata above the Pebble Bed are typically an upward-fining succession of silty and shelly grey-brown mudstones containing siltstone lenticles. The following Lower Grinstead Clay (Figures 10 & 11) yields spores, pollen, wood fragments, microplankton, rare foraminifera, abundant ostracods and molluscs (Batten 1973, Allen 1989). These confirm the readvance of a fresh/brackish-water lake/lagoon complex into the sub-basin, fringed by a retreating pebbly shoreline of reworked braidplain debris. As before, there are indications of extremely shallow water and local emergence (e.g. an *Equisetites* soil bed and a sun-cracked ironstone layer at Philpots Quarry; Allen 1989; Figure 11). The Grinstead Clay Formation encloses the Cuckfield Stone Member – a fine-grained sandstone body ranging up to about 5m in thickness (Figure 2). This is probably a small lake fan-delta like the Cliff End Sandstone in the Wadhurst Clay. At Freshfield Lane Brickworks, it cuts sharply down to within a metre or so of the Top Lower Tunbridge Wells Pebble Bed (Gallois & Worssam 1993). The contrasting scenario at Philpots Quarry some 6km to the northwest where the change is gradational, may be a more distal 'overspill' of the same fan-delta. Formerly seen at the Freshfield Lane site, the highest part of the Upper Grinstead Clay Member includes reddened and colour-mottled mudstones (Gallois & Worssam 1993). As at the top of the Wadhurst Clay, these indicate a return to intermittently emergent lake-margin or floodplain environments. The change thus

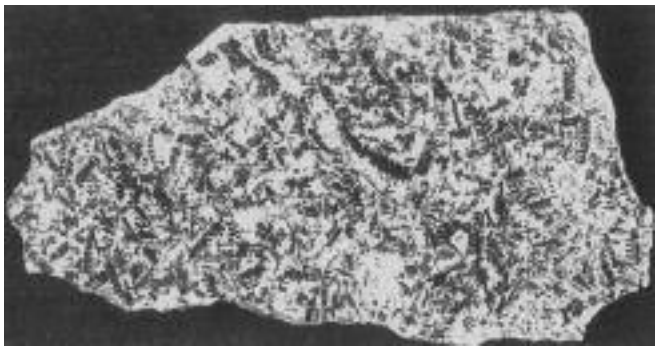

Figure 13. Pinnae of the fern *Weichselia reticulata* (Stokes & Webb) in ironstone concretion, Lower Weald Clay (below BGS Bed 3), Smokejacks Brickworks, near Ockley, Surrey. Maximum length of specimen is 28cm. Photograph supplied by Dr Ed Jarzembowski (Maidstone Museum).

foreshadows the Upper Tunbridge Wells Sand Formation (see below). In the eastern Weald, the Grinstead Clay is unrecognized (Topley 1875, Gallois & Edmonds 1965) and the undifferentiated Tunbridge Wells Sand Formation there is probably made up of a number of coalescing fan-deltas.

Upper Tunbridge Wells Sand Formation

In the central and western Weald, where it is discretely recognizable, the Upper Tunbridge Wells Sand Formation is locally up to around 100 m thick and overlies the oxidized top of the Grinstead Clay (Figures 2 & 3). It differs from the preceding sand formations in the development throughout of fine-grained distal alluvial facies (Allen 1975). Freshfield Lane Brickworks exposes the lowest 20-30m or so of which are dominated by brown, green and red-mottled mudstones, thin siltstones and fine-grained sandstones. Biogenic remains at that site include burnt wood fragments, plant stem/root traces and pond-mussels. The apparent absence of braidplain facies suggests that this phase of Londinian uplift was modest. Accordingly, the overlying Weald Clay Group (Figures 3 & 4) was deposited against the backdrop of a tectonically quiescent, passively decaying London massif.

Weald Clay Group

The Hastings Beds–Weald Clay junction is thought to equate broadly to the Valanginian-Hauterivian Stage boundary (Allen & Wimbledon 1991; Figure 3). The Weald Clay can be broken down into megacycles (Allen 1975; Table 1), but these are much more variable and poorly defined than those of the Hastings Beds. The alluvial phases are typified by associations of oxidized mudstone and silt enclosing metre-scale fine sandstones, deposited in distal meanderplain and lake/lagoon margin settings. As in the Hastings Beds, the alluvial intervals are separated by considerable thicknesses of relatively fossiliferous, commonly grey-coloured, dominantly argillaceous strata of lacustrine/lagoonal origin (Topley 1875, Allen 1975, Worssam 1978). The argillaceous intervals commonly feature metre-scale alternations of laminated, often shelly mudstone and bioturbated silt enclosing flute and gutter casts (Prentice 1969). The latter are either silty or finely sandy like those of the Wadhurst and Grinstead formations, and may be pebbly and/or glauconitic. Much of our knowledge of the Weald Clay comes from the western Weald (Figures 1 & 4), where large claypits have been opened up for the brick industry. These sections continue to yield many fossils including plants, insects and dinosaur remains (Figures 13 & 14). The alluvial facies are best

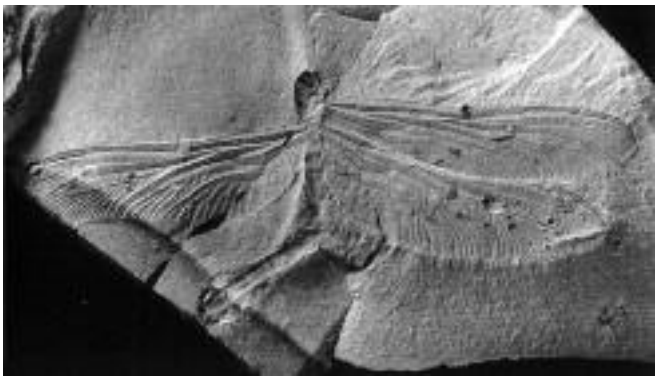

Figure 14. 'Hawker' dragonfly (*Valdaeshna surreyensis* Jarzembowski) in phosphatic concretion, Upper Weald Clay (BGS beds 3a-3c interval), Auclaye Brickworks, near Capel, Surrey. Wingspan is approximately 90 mm. Natural History Museum specimen In. 64632b. Photograph supplied by Dr Ed Jarzembowski (Maidstone Museum).

developed in this region, where Allen (1975) recognized a number of megacycles (Table 1).

The lower, alluvial phase of western Weald megacycle I is marked by the sandstones of the Horsham Stone Member (British Geological Survey (BGS) Bed 1) near the base of the Lower Weald Clay Formation (Figure 4, Table 1). These have long furnished roofing slabs in the Horsham area of West Sussex. The upper part of the Horsham Stone is still exposed in a shallow quarry and stream northeast of Slinfold, West Sussex (Slinfold SSSI; TQ125312-125319). Here, it comprises interbedded mudstone and fine-grained calcareous, locally trough cross-laminated sandstone.

The tourmaline-rich Horsham Stone and younger Weald Clay sandstones are important keys to our understanding of the megacycles. Significantly, they indicate derivation from the tourmaline-rich Cornubian massif in the west that was dominated by strongly folded Carboniferous rocks overlain by relatively undeformed Permo-Triassic redbeds (Allen 1981; Figure 5). Armorican detritus is virtually absent and Londinian scarce. The sandstones are probably the fringes of large fans built out from Cornubia and suggest periodic uplift of that massif as a primary cause of Weald Clay megacyclicity. The fans spread across Wessex and the Wessex-Weald 'axis' into West Sussex, but did not reach the edge of Londinia (Allen 1975).

Overlying the Horsham Stone, the argillaceous phase of megacycle I is typified by the roughly 20m succession of grey-brown mudstone, siltstone and shelly limestone beds in the range of BGS Bed 2 at the Langhurst Wood Road Brickworks pit, approximately 4km north of Horsham, West Sussex (Warnham SSSI; TQ180353). Prentice's metre-scale mudstone-silt interbeds mentioned previously are evident in parts of the succession and suggest periodically increased runoff into the Weald Clay lake-lagoon complex. Siltstone and fine sandstone lenses show a range of sedimentary structures including groove casts, tool marks and invertebrate burrows. The mudstones preserve suncracks at several levels. They also yield many molluscs ranging from fresh/brackish-water gastropods and bivalves (notably the corbiculid *Filosina*) to the near-marine cassiopid gastropod *Paraglauconia*. Lower Weald Clay 'brackish-marine' horizons

Table 1.Nomenclature used for western Weald Clay megacycles, their sand members and beds, with equivalent IGS [=British Geological Survey] bed numbers. Reproduced by permission of the Geologists' Association from *Proceedings of the Geologists' Association*, Allen P, Wealden of the Weald: a new model, 86, p.429, Appendix II. © 1975 The Geologists' Association.

	Member/Bed	I.G.S. Bed No.
MEGACYCLE VI (incomplete)	Desmoor Sand	11c
	— —	11b
	Pratsham Sand	11a
MEGACYCLE V		
	large-*Viviparus* limestone	10
	— —	9c
	Sayerscroft Sand	9b
	Newdigate Pebble Bed here?	
	Jayes Park Sand	9a
MEGACYCLE IV		
	large-*Viviparus* limestone	8
	Ewhurst Pebble Bed	
	Grayswood Sand	7i
	Pond Copse Sand	7h
	Noddings Sand	7g
	Nethersale Sand	7f } Fernhurst
	Northchapel Sand	7e } Sand
	— —	7d
	Lurgashall Sand	7c
	Park Mill Sand	7b
	Ebernoe Sand	7a
MEGACYCLE III		
	large-*Viviparus* limestone	6
	Kirdford Sand	5f
	— —	5e
	— —	5d
	Alfold Sand	5c
	— —	5b
	— —	5a
MEGACYCLE II		
	large-*Viviparus* limestone	4
	Wisborough Sand	3e
	— —	3d
	Billingshurst Sand	3c
		3b
	Okehurst Sand	3a
	Clockhouse Sand	
	Gossops Green Pebble Bed	2b
	Whitehall Sand	
	Geerings Sand here?	
MEGACYCLE I		
	small-*Viviparus* limestones	2a, 2b
	pebble bed	
	Upper Horsham Stone	1b } Horsham
	Lower Horsham Stone	1a } Stone

such as these record the highest salinities in the Weald Sub-basin since Purbeck times. They gain abundance in the northern Weald, suggesting that the marine influence was from a northern Boreal Sea via the Cornubia-Londinia gap or even across the eroded stump of Londinia itself (Allen 1975, Worssam 1978; Figure 5). The cassiopids are of Tethyan origin, raising the likelihood of an additional southern marine connection (Allen 1989). Shelly limestones (comprising BGS Bed 2a) are conspicuous in the lower part of the Langhurst Wood Road succession. They are interpreted as sheets of shell debris, deposited by storms on the periodically flooded mudflats around the lakes and lagoons (Radley 1999).

At Clockhouse Brickworks, Surrey (Capel SSSI; TQ176387) the lowest exposed beds are also grey mudstones and siltstones of megacycle I. They lie above the range of BGS Bed 2 as seen at

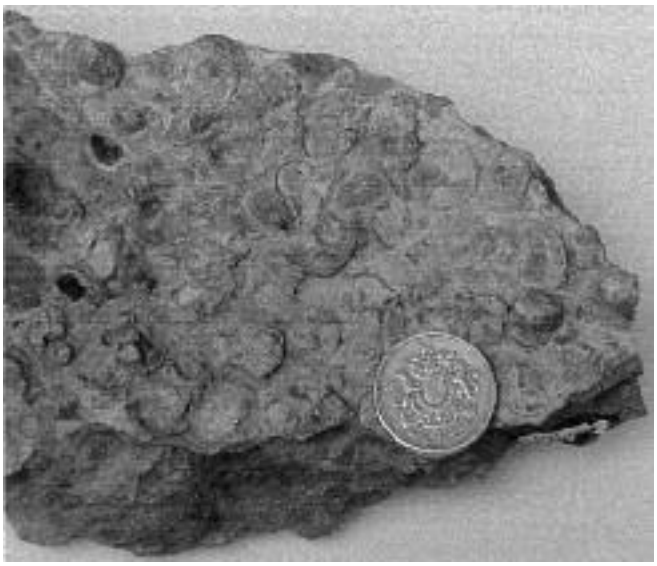

Figure 15. Weathered Large-'*Paludina*' limestone ('Bethersden Marble'), made up of pond-snail shells (*Viviparus fluviorum* (J. Sowerby *non* de Montfort)). Upper Weald Clay, Bethersden, Kent. Warwickshire Museum specimen G1185/3.

the Warnham SSSI (Figure 4, Table 1). This site and others nearby have yielded fresh/brackish-water molluscs, ostracods, conchostracans, fish debris, dinosaur bones, ferns, burnt wood and a rich aquatic/terrestrial insect fauna (Jarzembowski 1991; Figures 13 & 14). The overlying reddened and colour-mottled mudstones provide the first hints of renewed Cornubian uplift, foreshadowing megacycle II. They enclose the tourmaline-rich, *Beaconites*-burrowed Clock House Sand Member (BGS Bed 3, Figure 9) and are capped by another thin sandstone, thought to be the lowest part of the Okehurst Sand Member (BGS Bed 3a). This is currently taken as the base of the Upper Weald Clay Formation and of the Barremian Stage in the northwestern Weald (Ross & Cook 1995, Ross, in Rasnitsyn *et al*. 1998; Figure 4). It is well exposed in a stream section (Billingshurst SSSI; TQ078276-079277), 14 kilometres southwest of Clockhouse Brickworks. There it comprises several metres of interbedded argillaceous silt and sandstone above a 'raft' of lignitic plant debris. Radiometric dates from the abundant tourmaline and muscovite grains found there provide evidence for an ancient Cornubian-Armorican basement over southwest Britain and northwest France, bearing a strong metamorphic overprint (Allen 1975). Roughly coeval sandstones, gravels and plant debris beds in the Wessex Sub-basin (Dorset – Isle of Wight coastal sections) provide evidence for powerful floods caused by heavy rainfall over Cornubia, and due to Cornubian uplift (Allen 1989). The Okehurst Sand could be a distal expression of one or more of these events.

The argillaceous phases of the Upper Weald Clay include beds of so-called Large-'*Paludina*' limestone, made up principally of shells of the pond-snail *Viviparus fluviorum* (J. Sowerby *non* de Montfort). In the past, these limestones were quarried for building stone and when polished, under such names as Petworth, Bethersden and Sussex Marble (Figure 15). The shells appear to have accumulated in a range of settings, including desiccated ponds and along lake shorelines (Allen 1989, Radley 1999). BGS Bed 4 is one such limestone, near the top of western Weald megacycle II. It outcrops in road banks 2 kilometres southeast of

Billingshurst, West Sussex (Coneyhurst Common SSSI, TQ101244).

The return to marginal lacustrine/alluvial facies at the base of megacycle III is evidenced by the grey, green and brown mudstones and siltstones dug at Smokejacks Brickworks, southwest of Ockley, Surrey (Ockley SSSI, TQ113374). Siltstone lenses and ironstone concretions there have yielded a rich aquatic and terrestrial fauna, including molluscs, ostracods, insects, fish remains and dinosaur bones (Ross & Cook 1995). Plant remains are also abundant and include burnt fragments of ferns and the possible early angiosperm *Bevhalstia pebja* Hill. Professor Ed Jarzembowski's palaeoentomological studies (e.g. Jarzembowski 1995 and references therein) show that the Weald Clay insects were derived largely from woodland habitats and point to a warm-temperate or subtropical climate. The Smokejacks site is also well known as the source of the theropod dinosaur *Baryonyx walkeri* Charig & Milner (Benton & Spencer 1995). At the top of the section, the Alfold Sand Member (BGS Bed 5C; Figure 4, Table 1) has yielded sauropod as well as *Iguanodon* bones (Rivett 1953), and points to low-stage stranding of floodplain debris on small delta-fan sand bars.

The Netherside Sand Member (BGS Bed 7f, Table 1) belongs to the lower, alluvial phase of western Weald megacycle IV (Allen 1975). It is exposed for example in stream gorges at Fernhurst, West Sussex and near Chiddingfold, Surrey (Fernhurst SSSI; SU 892288 and Chiddingfold SSSI; SU 942338-944343). Dr Andrew Ross has presented convincing structural and biostratigraphic evidence suggesting that BGS Beds 8-11 (uppermost Weald Clay) are merely faulted sections of 6 and 7 (Ross, in Rasnitsyn *et al.* 1998). Thus western Weald megacycles V and VI (Table 1) may not exist and the Netherside Sand may lie close to the Wealden top. Bookhurst Tileworks (Cranleigh potential SSSI; TQ076395) exposes a Large-'*Paludina*' limestone overlain by several metres of shaly ostracodal mudstone. The latter encloses an impersistent pebble bed, comprising grains and pebbles of black chert (probably Lower Carboniferous in age), quartz and quartzite, in a glauconitic matrix. The glauconite is fresh (P. Allen, personal communication), suggesting input by marine inundation. Several similar pebble beds have been identified in the Weald Clay of the northern Weald (Table 1), providing further support for a Boreal marine influence. The cherts and quartzes are possibly of Londinian origin, entrained en route (Allen 1975). The limestone bed was mapped by the British Geological Survey as BGS Bed 8a (Figure 4), but could equate to BGS Bed 6 in the light of Dr Ross's discoveries. Accordingly, the Bookhurst succession might equate to the higher part of megacycle III rather than IV. The highest beds of the Weald Clay are very poorly exposed. They are marked by further influxes of brackish-marine molluscs (Worssam 1978), foreshadowing the demise of the Wealden regime and regional transgression of the Lower Greensand sea in early Aptian times.

Summary

The Weald Sub-basin was the setting for non-marine environments of warm-temperate or subtropical aspect for approximately 15 million years of the early Cretaceous Period. Muddy, plant-fringed lakes and lagoons dominated the area and were inhabited by fresh to brackish-water invertebrates, fish, crocodiles and other aquatic vertebrates. River-borne sands periodically invaded the Weald, marking uplift of the surrounding source massifs. Dinosaurs periodically traversed the floodplains and lake shorelines. At first, in Hastings Beds times, much of the sandy outwash was derived from the London massif. A more distant, western, Cornubian massif became influential later on during Weald Clay times, as the London massif ultimately succumbed to erosion.

Acknowledgements

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Book review

Taphonomy: A Process Approach by Ronald E Martin, 1999, Cambridge University Press, 508pp £27.95 paperback, ISBN 0521598338

Taphonomy: A Process Approach purports to offer a comprehensive review of the field of taphonomy, the science of fossil preservation. The book describes how plant, animal and trace fossils form in oceanic, terrestrial and river settings and how this affects interpretation of the environment, ecology and extinction of past life forms and the environments in which they lived. The book has chapters covering: the science of taphonomy, biostratonomy (sedimentary history of fossils from death and decomposition), bioturbation, time-averaging, exceptional preservation, sedimentation and stratigraphy, bias within the sedimentary record and applied taphonomy. The book uses a process approach to the subject and reviews the taphonomic behaviour of all important taxa, both plant and animal. This book will be mainly of interest to advanced students and professionals working in palaeontology, stratigraphy, sedimentology, climate modelling and biogeochemistry. It was also designed to appeal to anyone interested in the preservation of fossils and the formation of fossil assemblages.

This relatively inexpensive book, sought to bring up to date in this interesting field, which borders between palaeontology and sedimentology. The author explains in the preface that taphonomy "is concerned with the information content of the fossil record and the processes by which fossils are incorporated into the fossil record." The book is written in the style of a series of extended and professional review papers. Thus it is difficult to read unless one is familiar with the terminology (no glossary is supplied). A book integrating palaeontology and sedimentology is much needed as, in general, research in these two fields rarely uses data from the other discipline to its fullest extent; unfortunately, this book does not fulfil its potential.

Jacqui Malpas PhD

Back to basics in La Gomera : an introduction to the geology and guide to selected field locations

Duncan Woodcock

Introduction

The island of La Gomera is one of the smaller and lesser known islands of the Canary Islands archipelago. It lies around 30km west of Tenerife, from which it can be reached by a modern hydrofoil ferry service. So far, La Gomera has escaped the development associated with mass tourism found on some of the larger islands.

La Gomera is roughly circular in shape, with an area of around 370km^2. Volcanism ceased some 4Ma ago and since then the landscape has been extensively eroded, resulting in the rugged topography observed today. The centre of the island is occupied by a plateau with an altitude of around 1000m that is covered in semi-tropical forest. This plateau area is surrounded by seaward sloping terrain that has been incised by deep valleys (barrancos), leaving a series of radial ridges (Figure 1) that usually terminate seawards as steep cliffs.

Figure 1. View inland from TF711 road, approximately 8km from San Sebastián, over one of the radial ridges typical of the area surrounding the central plateau. The salic intrusion of Roque Ojila is visible on the horizon in the centre.

Uplift and erosion have exposed a sequence of rocks from the plutonic basement rocks to the most recent phase of volcanism. The purpose of this paper is to provide a brief introduction to the geology of La Gomera and to present a selection of itineraries where different aspects of the geology can be studied at first hand.

Logistics

The size of the island is deceptive! Although only 25km in diameter, the rugged terrain forces the roads to twist back and forth, making for slow progress and requiring concentration from the driver. The best way to explore the island and its geology is to make use of the well-maintained network of footpaths, inherited from bygone days when there were no roads and the island supported a much larger rural population. Large scale maps are readily available, such as the excellent 1:40,000 scale map from Discovery Walking Guides (Brawn 2001). A number of useful walking guides to the island have been published such as Brawn (2000) and Rochford (1999).

La Gomera is considerably wetter than the more low-lying islands of Lanzarote and Fuerteventura! The climate is determined largely by the interaction of the topography with the NE Trade winds: thus the northern parts of the island tend to be cloudy while the southern side of the island tends to be drier and sunnier. The altitude of the central plateau often coincides with saturation level in the atmosphere, consequently it is usually enveloped in thick fog.

Geology

Overview

The geological development of La Gomera is less well understood than that of the main Canary Islands, in part due to the rugged terrain, dense vegetation and the scarcity of good exposures. The following outline represents a summary of the current consensus (Carracedo & Day 2002).

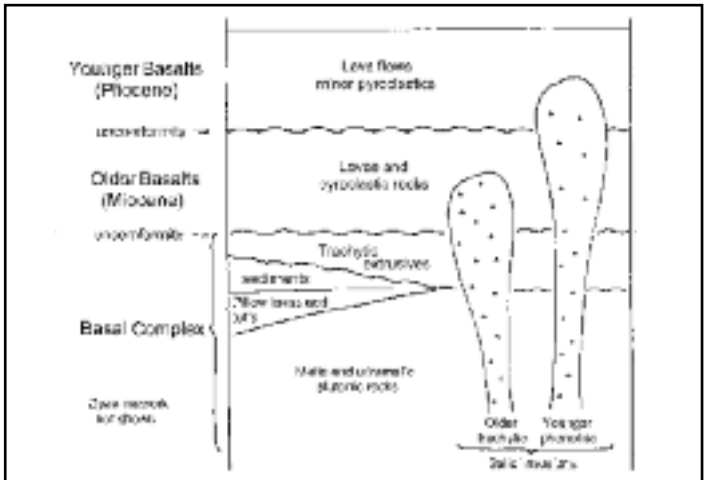

Figure 2. Overview diagram of the "stratigraphy" of La Gomera.

(i) Development of the "Basal Complex", comprising mafic and ultramafic plutonic rocks together with volcanic and sedimentary rocks. The whole complex is cut by a dense swarm of dykes.

(ii) Subaerial eruption of the "Older Basalts": a sequence of basalt lavas and pyroclastics.

(iii) Tilting of the island to the south; erosion to expose the deeper Basal Complex in the north of the island and to cut deep barrancos.

(iv) Subaerial eruption of the "Younger Basalts": a sequence of basaltic lavas.

(v) Intrusion of the "Salic domes": a series of trachytic and phonolitic intrusions, possibly intruded in more than one phase.

Figure 2 summarises this outline of the geological development. A simplified geological map of La Gomera, based on Féraud *et al* (1985) and Bravo (1964) is presented in Figure 3. The following notes present the geology in more detail.

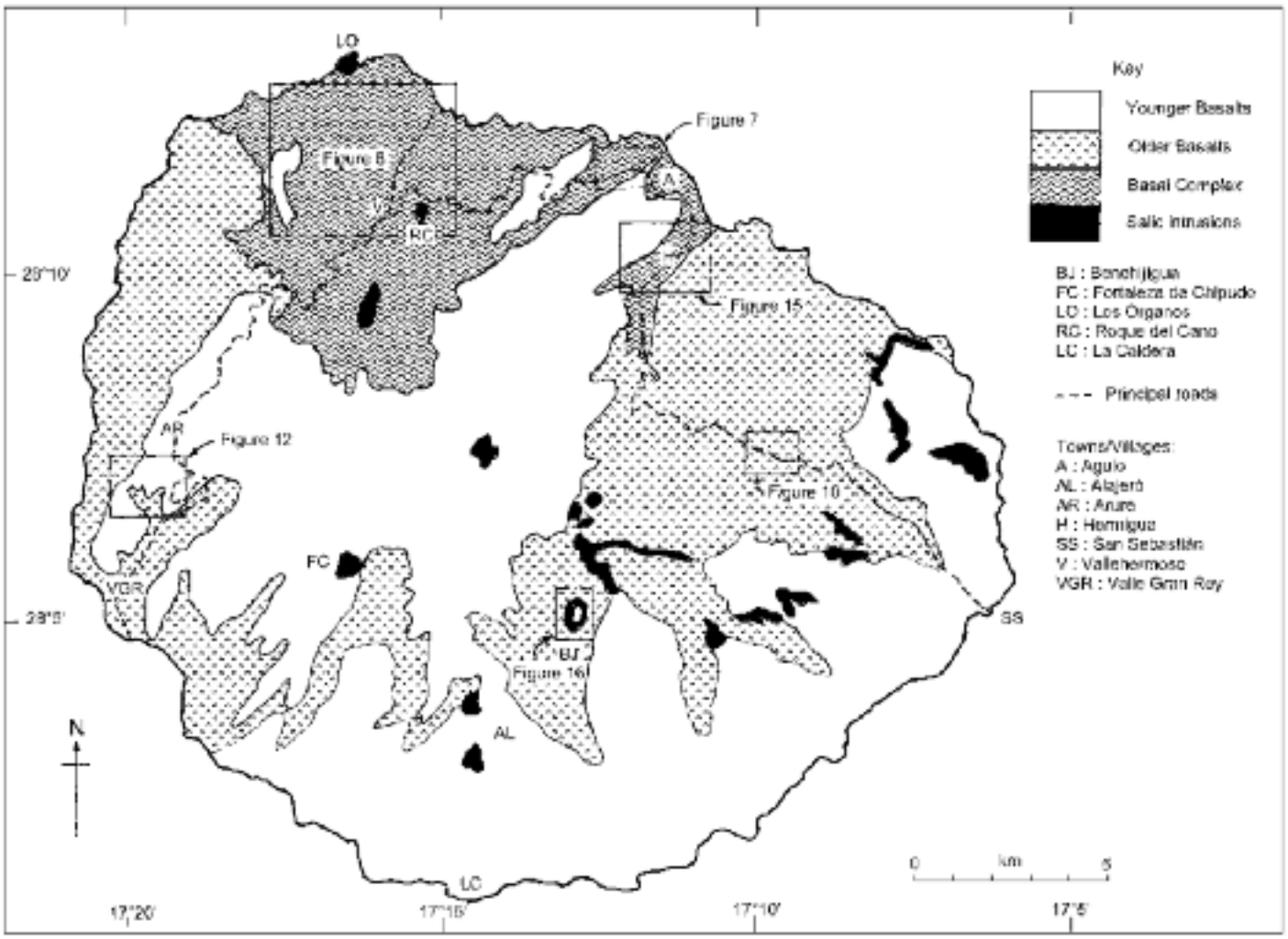

Figure 3. Simplified geological map of La Gomera, based on Féraud *et al* (1985) and Bravo (1964).

Basal Complex

The most comprehensive description of the Basal Complex is presented in Cendrero (1971a), with a detailed geological map in Cendrero (1971b). The Basal Complex comprises the following components:

(i) A series of plutonic mafic and ultramafic rocks. The ultramafic rocks include both peridotites and pyroxenites. The mafic rocks range in composition from olivine gabbros to alkali gabbros.

(ii) A series of submarine volcanic rocks, comprising basaltic pillow lavas together with basaltic and trachytic tuffs. These are associated with marine sediments including carbonates, shales and cherts, similar to the extensive exposures of similar rocks on Fuerteventura. The outcrop of these sediments is restricted to a small, relatively inaccessible area on the NW coast of La Gomera.

(iii) A series of trachytic and phonolitic tuffs, agglomerates and breccias that are exposed in the centre of the Basal Complex around the town of Vallehermoso.

(iv) A dyke swarm that intrudes the above components and comprises on average about 80% of the whole exposure of the Basal Complex. The dykes are mainly basaltic and range in width from 0.1 to 10m. In outcrop they display a complex cross-cutting relationship and often reduce the host rock to thin slivers between dykes. The dyke swarm was once considered to be a sheeted dyke complex associated with plutonic mafic-ultramafic rocks in an ophiolite suite. This origin for the dykes is unlikely because the dykes cut the whole Basal Complex sequence from plutonics to sediments. It is possible that the dykes were intruded during a period of crustal extension associated with a sudden increase in the rate of opening of the Atlantic Ocean (Cendrero 1971b).

Inland exposures of the Basal Complex are generally heavily eroded: Hausen's comment about being able to cut these rocks with a knife (Hausen 1971) is often remarkably accurate! The scarcity of good exposures, together with the pervasive intrusion of the dyke swarm has made it difficult to study the relationship between the various components of the Basal Complex.

Older Basalts

Subaeriel eruption of a series of basaltic lavas and pyroclastic rocks represents the main "shield-building" stage of the development of La Gomera. These rocks are dated at 12-8Ma (Cubas Padilla 1978a) and are often known as the Miocene Basalts in the literature. In detail these Older Basalts comprise three subseries:

(i) the Lower Older Basalts: a succession of relatively thin pahoehoe and aa lava flows

(ii) a pyroclastic sequence of tuffs and agglomerates: the "aglomerados poligénicos" (Cendrero 1971b)

(iii) the Upper Older Basalts: comprising lava flows with subordinate pyroclastic material.

Eruption of these Older Basalts ceased at around 8Ma and was followed by a period of intense erosion that carved out steep barrancos, producing a topography that was probably similar to the modern day topography of the island.

Younger Basalts

The Younger Basalts were erupted between 4 and 5Ma ago (Cubas Padilla 1978a), initially infilling the erosional topography cut into the older rocks. Many of the lower flows were constrained by the topography and cooled in thick, columnar jointed units (Figure 4). The whole sequence comprises a series of stacked horizontal lava flows. Most flows are of ankaramite basalt, with fresh olivine and pyroxene phenocrysts in a finer grained groundmass.

Figure 4. Thick basal flow of Younger Basalts showing well developed columnar jointing. TF711 road tunnel *c.*1km beyond Agulo.

The youngest volcanism on La Gomera is represented by a small volcanic cone at La Caldera on the coast south of Alajeró. This cone has the distinction of being the only recognisable constructive volcanic landform on La Gomera.

Salic intrusions

One of the most recent magmatic events on La Gomera appears to have been the intrusion of a series of salic bodies with a trachytic or phonolitic composition. In his description of the volcanology

Figure 5. Roque Cano: a plug-like phonolitic intrusion.

Figure 6. Fortaleza de Chipude: a dome-shaped trachyandesitic intrusion.

and geochemistry of these "domos sálicos", Cubas Padilla (1978a,b) considers that intrusion took place in two phases, with the trachytic bodies intruded before the phonolitic bodies.

The salic intrusions display a variety of shapes, from the plug-like phonolitic intrusion of Roque Cano (Figure 5) and the dome shaped trachyandesitic intrusion of Fortaleza de Chipude (Figure 6) to the trachyphonolitic ring intrusion at Benchijigua.

Geological Excursions

Until recently there was no geological excursion guide available for La Gomera. A recent publication (Carracedo & Day 2002) contains a limited guide that comprises mainly an extended road tour of the island. In my opinion, the best way to study the geology is to park one's vehicle at a strategic location and then get out and walk! The following excursions thus complement those recently published. They are grouped according to the main geological subdivisions used in Figure 2 & 3.

Basal Complex: Excursions

The Basal Complex is poorly exposed and in general heavily weathered; exposures of fresh rock are restricted to rare accessible coastal exposures and recent road cuts. The two excursions presented below are both in the heavily dyked mafic-ultramafic rocks that comprise the bulk of the Basal Complex.

Excursion 1: Main Road (TF711):Agulo- Las Rosas

My visit to La Gomera was timed to coincide with a major programme of roadworks in the mafic-ultramafic part of the complex (get a life, I hear you say!) It was thus relatively easy to access and examine fresh exposures and to collect in-situ material suitable for the production of thin sections. Figure 7 shows a sketch map of the locations visited.

A road cut at 28° 11.3'N/17° 12.1'W displays an assemblage of mafic and ultramafic rocks intruded by relatively few dykes. The

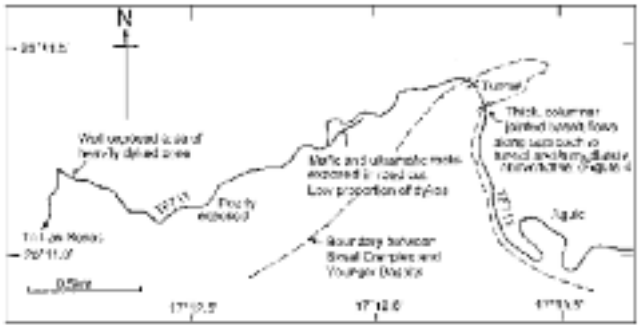

Figure 7. Annotated sketch map of exposures in the Basal Complex along TF711 road from Agulo to Las Rosas.

dark grey, coarse grained ultramafic rocks display stubby black pyroxene and bottle green olivine crystals in hand specimen (HS) together with around 10% white felsic minerals and a few small but conspicuous crystals of biotite. In thin section (TS) there are large (2-5mm) subrounded cumulus olivine grains together with large cumulus clinopyroxene grains. The intercumulus space is occupied by small clusters of clinopyroxene, altered plagioclase and biotite together with accessory apatite and opaque mineral.

The mafic rocks present at the locality are gabbros with conspicuous biotite along with pyroxene in a felsic matrix. In thin section these rocks display large epidote crystals, presumably produced as the result of alteration of the plagioclase feldspar.

Excursion 2: Vallehermoso area

In this excursion, the relatively fresh mafic-ultramafic rocks that crop out along the TF712 road and in coastal exposures can be contrasted with the extensively eroded exposures of similar rocks inland. An annotated sketch map of the area is presented in Figure 8.

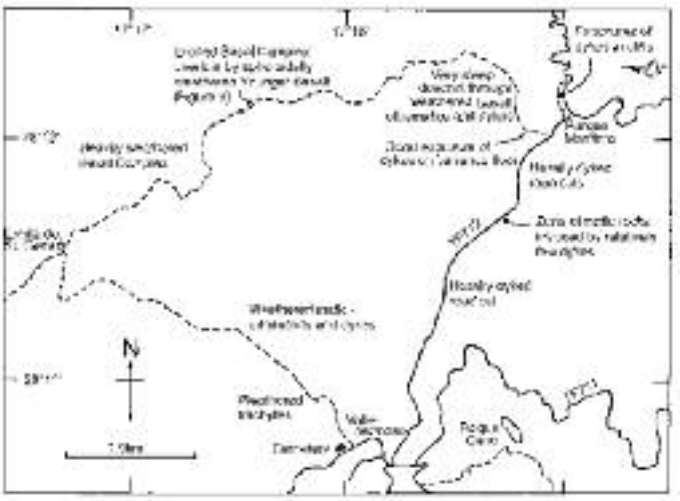

Figure 8. Annotated sketch map of the Vallehermoso area.

A track running NW out of the town of Vallehermoso starts immediately NE of the cemetery and gradually climbs to the Ermita de Santa Clara; initially over weathered trachytes and then over weathered mafic-ultramafic rocks cut by dykes. From Ermita de Santa Clara, a track runs ENE over heavily weathered Basal Complex along the Buenavista ridge (Figure 9), followed by a very steep descent down to the TF712 road immediately SW of the Parque Marítimo. There are excellent exposures of cross-cutting dykes with slivers of the mafic-ultramafic host rock exposed in the floor of the barranco immediately above the road and also in cliff exposures along a track running north from the Parque Marítimo. The TF712 back into Vallehermoso has a good selection of road cuts.

Figure 9. Spheroidally weathered exposure of Younger Basalts on the Buenavista ridge (see Figure 8 for location). Note the relatively unweathered core on the left, showing large dark pyroxene phenocrysts.

Older Basalts: Excursions

Two excursions are offered here: one to study the features of the lava flows, the other to examine a section in the pyroclastic sequence.

Excursion 3: Road loops on old TF711

Recent road improvements on the TF711 between San Sebastian and Hermigua have resulted in the removal of some of the more hair-raising hairpin bends and their replacement by three new road tunnels. The resulting abandoned sections of road are accessible and provide the opportunity to study road cuts in the Older Basalts in relative safety and tranquility. Figure 10 shows an annotated sketch map for two easily accessible road loops.

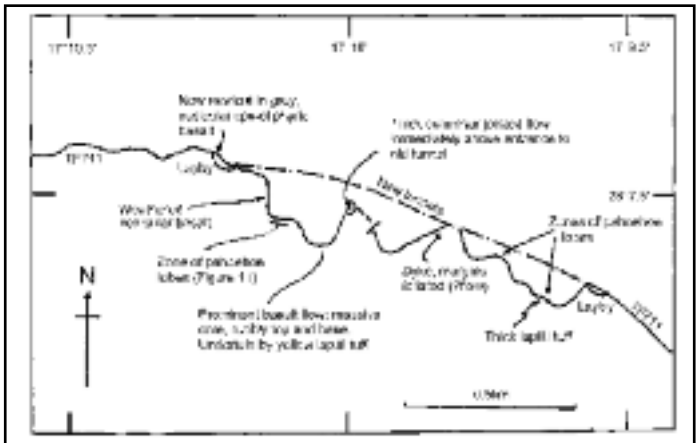

Figure 10. Annotated sketch map of abandoned road loops on TF711 cut in Older Basalts.

A typical sample of basalt from the recently excavated layby at 28° 07.5'N/17°10.2'W is grey, vesicular and porphyritic with fresh black pyroxene crystals and brown weathered olivine grains in a fine grained groundmass (Figure 11). In TS the clinopyroxene phenocrysts are unaltered and have a purplish tinge around the margins, while the olivine phenocrysts are invariably rimmed with red-brown translucent iddingsite. The groundmass comprises small tabular plagioclase, pyroxene, altered olivine and an opaque mineral.

Figure 11. Lobate pahoehoe flow in abandoned road loop. See Figure 10 for location.

Excursion 4: Arure - La Mérica ridge

This excursion in the west of the island concentrates on a small inlier of Miocene pyroclastic rocks (Figures 13 & 14) within an area dominated by the younger Pliocene basalts. In addition it affords spectacular views of the unconformity between the two basalt series in the east side of Valle Gran Rey. Figure 12 presents an annotated sketch map of the main geological features.

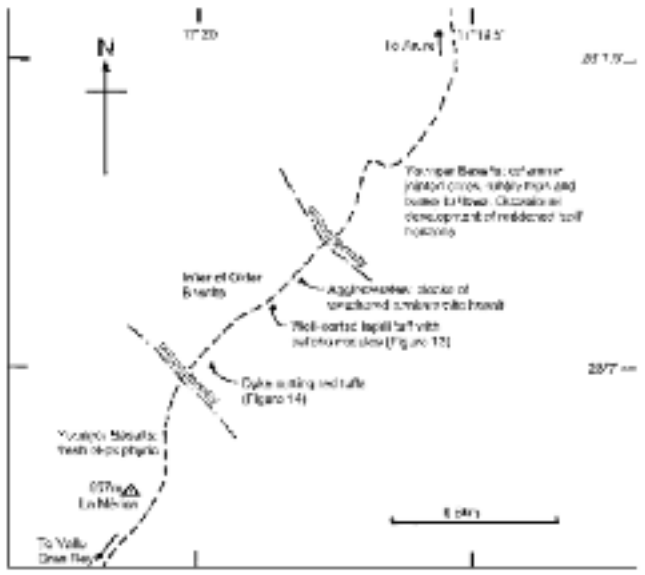

Figure 12. Annotated sketch map of Miocene inlier between Arure and La Mérica.

Figure 13. Well sorted lapilli tuff with round caliche nodules. Coin diameter *c*.2cm. See Figure 12 for location.

Younger Basalts: Excursions

Excursion 5: Escarpment above Hermigua valley

The ribbon development along the Hermigua valley is built on an inlier of heavily eroded Basal Complex that is overlain unconformably in the NW by a thick pile of Younger Basalts. These basalts form an escarpment over 300m high, comprising tens of individual horizontal flows stacked one on another. A steep path from the road above the Ibo Alfaro hotel (Figure 15) climbs right

Figure 14. Dyke cutting red tuffs. The harder rock of the dyke has weathered proud of the softer tuffs to produce a wall-like feature known locally as a taparucha. The vertical sides of the dyke are rough due to partial fusion of tuff fragments at the time of intrusion. Width of dyke *c*.0.5m. See Figure 12 for location.

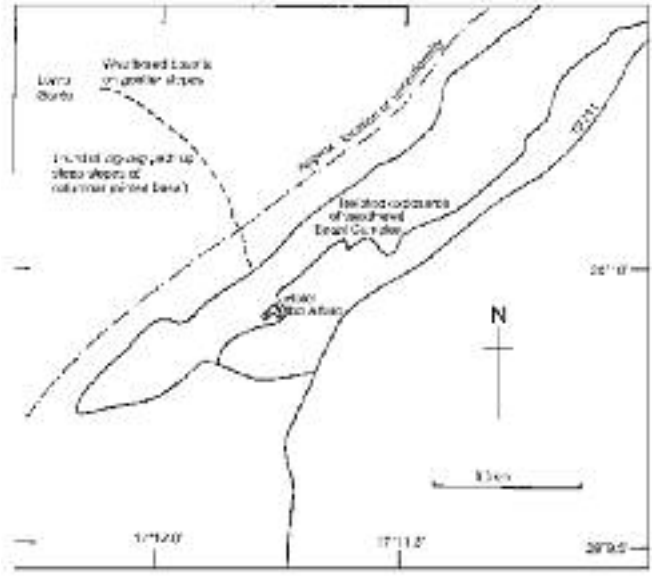

Figure 15. Annotated sketch map of the Hermigua valley, showing location of footpath up the Younger Basalt escarpment.

up the escarpment and allows the flows to be examined. Most flows have rubbly tops and bases, with massive, columnar-jointed cores. In some places, reddened layers are present between flows, indicating that in some cases there was a sufficiently long period of time between eruptions for weathering of the top of a flow to occur.

A typical sample of Younger Basalt from the centre of the lowest outcropping flow on the escarpment at 28° 10.1'N/17° 11.9'W is grey, non-vesicular and porphyritic with fresh black pyroxene

crystals and green olivine grains in a fine grained groundmass. TS examination confirms the identity of the phenocryst phases and shows the groundmass to consist of small plagioclase crystals in a sub-parallel alignment, together with small mafic and opaque mineral grains.

Salic Intrusions: Excursions

The salic intrusions are one of the most distinctive features of the landscape of La Gomera. Several of the most prominent ones can be examined at a distance from the road or the footpath network. The most famous intrusion of Los Órganos, a phonolitic body on the north coast that has developed spectacular columnar jointing, is only visible from the sea.

Figure 17. "Aerial" view of Benchijigua ring intrusion, looking west from the dirt road at Las Toscas.

Some intrusions can be examined at close quarters. The trachyandesitic intrusion of Fortaleza de Chipude (Figure 6) can be approached by a footpath from the road to the north. Access to the flat summit plateau involves a scramble up slabs of rock: it is easy to see why this location was one of the last strongholds of the original Guanche inhabitants in the face of the Spanish conquistadors. The excursion offered below is to one of the more accessible, yet unusual of the salic intrusions.

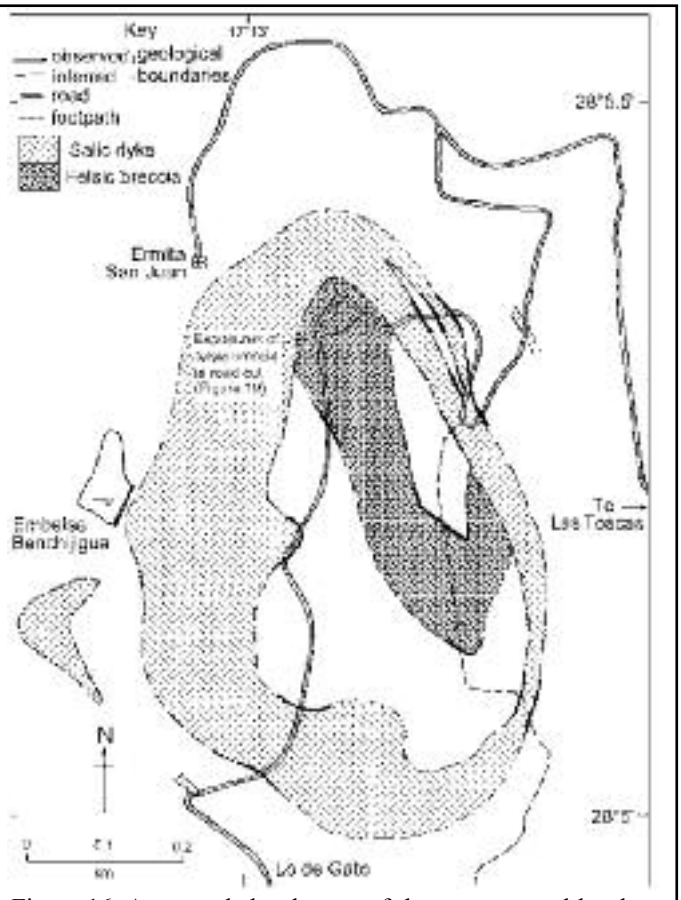

Figure 16. Annotated sketch map of the area covered by the Benchijigua ring intrusion. Solid geological boundaries refer to those observed during traverses along roads and footpaths. The chain lines indicating the extent of the intrusion and the felsic breccia are from Cubas Padilla (1978a).

Excursion 6: Benchijigua ring intrusion

Figure 16 presents an annotated sketch map of the area covered by the Benchijigua ring intrusion. Access is probably easiest by parking at Las Toscas on the main road to Playa Santiago, and walking in along the dirt road. This route has the advantage of giving splendid aerial views of the complete annular intrusion (Figure 17). The western side of the intrusion comprises a steep semicircular ridge of rock, with prominent radial fractures (Figure 18). The eastern side is much less prominent, being no more than a low ridge of rock.

Figure 18. Prominent radial fractures in the western wall of the Benchijigua ring intrusion.

The new road to Lo de Gato runs right through the centre of the intrusion and provides excellent fresh exposure. A typical hand specimen from the intrusion is light grey and medium grained comprising felsic grains with sparse darker mafic grains. Examination of a TS shows tabular crystals of alkali feldspar up to 1mm long surrounded by a groundmass of small feldspar crystals with a distinct alignment (trachytic texture). The groundmass also contains a yellow-green/blue-green pleochroic Na-pyroxene together with biotite, apatite and opaque mineral grains.

Part of the area enclosed by the annular intrusion is occupied by a distinctive breccia that is distinguished from the basaltic breccias and agglomerates of the country rock by the presence of lightly coloured angular clasts of a material similar to that of the intrusion (Figure 19). The formation of this "felsic breccia" must have been intimately related to the intrusion of the ring dyke (Cubas Padilla 1978a).

Figure 19. Felsic breccia in the interior of Benchijigua ring intrusion. The breccia contains lighter felsic clasts as well as darker basaltic clasts. See Figure 16 for location.

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Book reviews

The Geology of Eigg by John Hudson and Ann Allwright, April 2003, Isle of Eigg Heritage Trust, 56pp (paperback), £5.00.

This small guide book describes the geology of Eigg "for all those interested in the landscape and natural history of the Hebrides". Little prior knowledge of geology is assumed and at the back of the book there is a glossary of geological terms and details of the geological succession on Eigg.

There are sections on geology and landscape, the geological make-up of the island and its place in the Hebrides, Jurassic rocks and fossils, Cretaceous rocks, the Tertiary Igneous Province, and the island's history during and since the Ice Ages. In the section "The Tertiary Igneous Province" there are explanations of lava flows, columnar joints, trap topography, amygdales, dykes and sills. Raised beaches and landslides are described in the section "During and since the Ice Age" with a simple and clear diagram of a landslide.

There is a fascinating chapter about the Sgurr, the prominent ridge in the south, and the controversial theories about its origin. The early arguments started in the 19th century and there is a diagrammatic sketch tracing the sequence of events as they are now understood of its formation since the basalt lavas were erupted about 60Ma ago. It is suggested in the book that the full history of the investigation "would make an interesting study of changing geological theories, attitudes, techniques and styles of presentation". The Further Reading list at the back of the book would make a good starting point for anyone interested in researching this.

The guide concludes with seven suggested excursions and there is a map with locations marked. Before the descriptions of the excursions there is a very good section on "Safety and conservation". The first four excursions would appeal to general visitors as they are fairly gentle walks with spectacular views and with plenty of interest for non-geologists. The geological features are described and there are suggestions for alternative routes for the more energetic. The final three excursions are described as "geologically rewarding localities".

This little book is full of interest and there are good sketches, maps, diagrams and photographs: at £5 it is a "must" for anyone visiting Eigg. At the moment it is available only from the shop on the island: this is a pity as it makes fascinating reading and is a real incentive to visit the island.

Elizabeth Maddocks, BA (Open)

Rivers and Floodplains: Forms, Processes and Sedimentary Record by John S Bridge, 2003, Blackwell Science Ltd., 491pp, £34.99 (paperback) ISBN 00632064897.

This book brings the mechanics, geometry and patterns of sedimentation found in present-day fluvial environments together with the record found in the deposits of ancient rivers, and hence the interpretation of these deposits. It is a very useful handbook for anyone working on this sort of material.

The first three chapters deal with the basics, and the maths needed! Chapter headings 'Fundamentals of water flow' and 'Fundamentals of sediment transport' describe exactly what the chapters contain: good descriptions of water flow and the parameters, and a sound overview of sediment transport. The book is very well structured – after the introductory chapters the subject is developed, describing sedimentary structures, alluvial fans, floodplains, channel movements and then long-term, large scale evolution of fluvial systems. The case studies in the long-term chapter are good examples and useful. The approach is process based, concentrating on understanding how rivers behave, and then applying this to real examples. It is aimed at 'senior undergraduates' (interesting term for the OU?!) and graduate students, and certainly isn't a first year text. It gives a good sound background and then offers direction elsewhere for more extensive reading.

The two appendices are excellent practical aide-memoires, and I have been using the extensive list of references to follow up material for my own work. It's an excellent reference volume for anyone working on present day or ancient river material, can I keep it, please?!

Jenny Bennett OU Tutor, MPhil, PhD student

Aspects of particle technology applied to particulate deposits and to some of the properties of soils related to a specific chalk subsoil

Roger Hedge

In an earlier paper (Hedge 1995), I showed how some aspects of particle technology, taken from the field of Chemical Engineering, could be applied to the understanding of sampling procedures in geology and in subsequent laboratory work-up practices.

This paper outlines some features of the volumetric behaviour of particles of different size ranges and bulk densities when mixed and deposited. The drainage and porosity characteristics of particle assemblages are touched upon in this context. This is relevant to the modelling of oil reservoirs and to much of engineering geology. The way that particle size and size ranges alter when subject to industrial mechanical grinding is given and put in the context of ploughing of a chalk subsoil. The possible relationship to weathering and water reduction of particles is reviewed.

Some data is given relating to aspects of the above, based on two extreme types of soil material that exist in the chalk-based Bascomb Down area of Hampshire, south of Petersfield, as taken during an archaeological experiment started at the Butser Ancient Farm. The first is a very fine hill-wash material that collects at the foot of slopes or in dips. As shown later, this material dissolves almost entirely in hydrochloric acid and it is later argued that this may be outwash from the gross material that exists in the plough zone, resulting from both weathering and to a lesser extent from ploughing over the millennia. This is an example of localised sorting. The second material is in fact the gross overburden (soil) existing as a result of geological processes, weathering and field cultivation.

It is worth repeating the key assumptions from the earlier paper. In theoretical and experimental studies, it is presumed that every particle has an equal opportunity of being at a given location in an assemblage. It is known that, even in industrial equipment designed to meet this objective, there is an upper limit to approaching this situation. Real geological systems are generally regarded as segregated and sorted. However, the principles discussed are still applicable to understanding soil properties both in engineering geology and in interpreting the behaviour of sediments and other deposits.

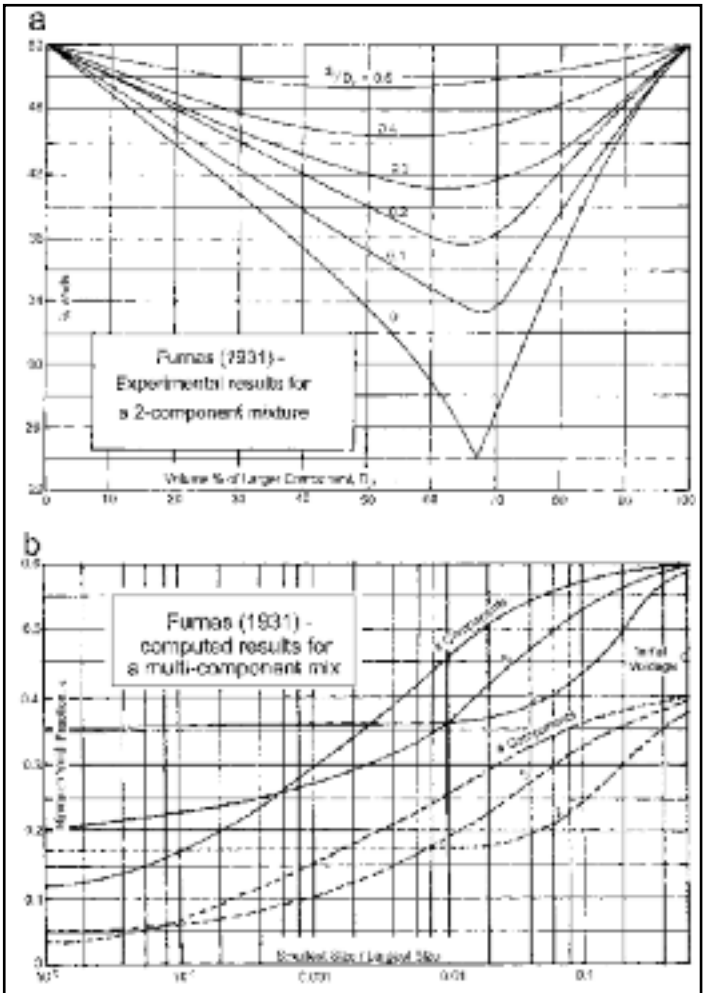
The behaviour of mixtures of particles

The particle size and size mix is regarded as an essential feature of any soil and influences its characteristics in many ways. The bulk density and the pore volume (voidage) is dependent on these two factors in a somewhat complex way, which is not easily predicted.

This is readily illustrated in the following two diagrams for relatively simple idealised assemblages.

Furnas (1931) studied experimentally the voidage in binary systems of varying particle size ratio (d_p/D_p), as shown in Figure 1a, for particles of equal initial voidage of 50%. He found that the minimum voidage varied both as the initial size ratio varied and as the proportion of each component varied. Further, if the initial component voidages were not the same, then the minimum voidage was **less** than the volumetric weighted average.

He derived analytically some results for mixtures of 3 or 4 components, again for the simple situation of spheres of different sizes. The results for two components of initial voidages 40% and 60%, with different finer materials introduced are given in Figure 1b. Furnas' detailed equations, for these derivations, can be got from the original reference or from Zenz & Othmer (1960).



Figures 1a & 1b. Furnas' results for the voidage of mixtures of different particle sizes.

The fact that voidage can vary so dramatically is a clear illustration of why even the most modest disturbance, post-deposition, creates variations that can never reflect the original situation. In engineering geology, it is a principal factor in why it is so hard, for example, to repair trenches dug in roads, without subsequent subsidence.

Add to this the fact that cylindrical parallelepipeds (cylindrical, not hexagonal, pencils, say!) close pack with a voidage of 9.5%, in contrast with spheres which close pack at 47.6%, while a loosely tipped stack of pencils could have a voidage as great as 90%, then it is clear that no meaningful expectation of values for voidage could be developed from theory for naturally occurring particles of all sorts of shapes and sizes. This has a considerable

impact on modelling the properties of particle assemblages. It also inevitably impacts on the methodology for measuring bulk volumes for this and other purposes, of course, as discussed next.

The packing of materials of varying size fraction depends very much on the way materials are brought together, "mixed" and compacted. The routine test approach is to collect data for material both as “freely tipped" and as compacted by "tamping". This is demonstrated in this data by illustrating how the bulk volumes of mixtures of various size fractions relate to the values for individual fractions, along with some results for tamping a given mix (Table 1). The data is signal in showing to the uninitiated just how large such physical differences can be.

For those unfamiliar with the niceties of mixing particle assemblages, the process of mixing is conventionally carried out in a tumbling “cube”. This is a cubical container rotated about a drive axis aligned across any internal diagonal. In the absence of such a piece of apparatus, I used a 2 litre ice cream container, with its lid, and rotated it by hand ... but then I have been doing such things for decades and, now I no longer have access to the formal equipment, I am well able to improvise without meaningfully spoiling the results!!

A range of measuring cylinders was used to determine the relevant volumes. Because of the range of sample sizes, cylinders of different sizes were employed. A necessary minor caution, then, is that for the smallest cylinders there may have been some limited “wall effects” i.e. the drag on the particles closest to the wall could decrease the apparent bulk density by a smidgen.

Porosity and drainage

It is now appropriate to discuss where water or oil resides in a particle assemblage and how it moves during drainage and/or drying. There are two factors of importance.

When a bed is saturated, the gross mass of fluid within the pore free space (including any micropores, which are not normally reflected in bulk density results) forms a continuum and flows as through a complex of channels. Once the pores start to empty, the fluid is trapped in the “bridges” between particles and the additional surface tension effects have a major impact on drainage and flow.

In the case of soils, this is the main reason why dry soils form “hard” lumps which are difficult to break down. Since the water in these “bridges” has a long residence or contact time, this film may be altered by dissolved ions from the contact solid.

The following diagrams illustrate qualitatively how a liquid drains from pores leaving "bridges" held in place by surface tension at contact points (primary recovery of oil is from the filled pores of reservoir rocks, while secondary and tertiary methods remove the oil "trapped" in the bridges).

It should be appreciated that the schematic in Figure 2 is a 2-D representation of a 3-D situation and that "pores" will empty at different levels according to the size and shape of the interconnecting "channels" that exist. The exact dimensional features of these channels and the degree of interconnection will, as already pointed out, be a function of the sizes, size ranges and shapes of all the particle types present. It is worth noting that the surface tension forces which retain the liquid as bridges between particles and as micro-films on the surface of particles are also involved in moving the smaller/smallest particles through the particle array, sometimes called "sieving", until an equilibrium is reached.

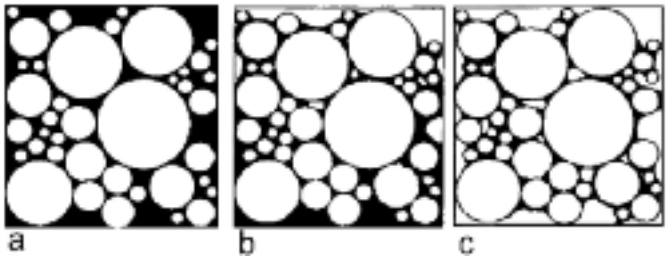


Figure 2. Schematic of the drainage of liquid from an array of particles.

The underlying chemistry of the soil is therefore likely to be of significance. The fact that material may dissolve in pore water is known to affect engineering properties. Clays readily exchange ions under suitable conditions, the commonest exchangeable ions being calcium, magnesium, potassium and sodium. As the ions change, so the properties of a layer may change.

A historic example comes from the San Francisco World Fair in 1919 (Leggett 1962). A prominent feature was a 7-acre lagoon, which had been lined with a calcium clay of loamy texture. Tests with fresh water showed rapid leakage. Laboratory exploration showed that by filling the lagoon with sea water sodium ions would exchange and increase the water-tightness. This proved to be the case.

Another factor, even in the case of calcium-rich clays, known to Civil Engineers engaged in road construction, is their tendency to form compacted, essentially water-impervious layers, where heavy machinery has been driven over a surface under preparation while saturated with water.

It is important to appreciate how the resistance to flow, and hence any effects on the rate of "free" drainage, may be influenced for an array of the above type. The voidage may be taken as e. Then for uniformly sized spheres, the flow rate is proportional to $e^3/(1-e^2)$ (Coulson and Richardson 1959). Thus for a change in voidage from 0.5 to 0.6 (say) from one part of a "site" to another, the flow rate for a given force (gravity, injection pressure or whatever) will alter by a factor of 2.7. This gives some idea of the potential variability in drainage in any and every type of sedimentary deposit.

In this context, it should be repeated that particle shape, size range and orientation will also influence the drainage pattern.

The most general statement illustrating these effects is given by Zenz and Othmer (1960):

> "The more irregular the particle shape and the wider the particle size distribution the more difficult it is to orientate particles into denser and more compact configurations."

Characterisation of the test soils

Firstly, it must be emphasised that "clay" is a particle size definition **not** a reference to fine particles of a particular chemical type (Leggett 1962). Customarily clays are of size 2 microns and smaller, their chemistry being that of the solid rock from which they have been derived. Changes in properties may arise as a result of all the many processes prior to, during and since transportation from the site of origin to their final location.

A few comments are now necessary to cover the sieving methodology and how the given results were obtained.

Table 1. Bulk volume and density data for “gross” soil.

Total Sample	Volume (ml) for fraction (**)	Weight (g) for fraction	Volume (ml) of mixed fraction	Density g/ml	Specific volume (l / kg)
> 8mm	80 (100ml)	73.47		0.918	1.089
>5.6mm	50 (100ml)	43.89		0.878	1.139
> 4mm	50 (100ml)	50.66		1.013	0.987
> 10#	110 (sum of 2 x 100)	102.6		0.933	1.072
< 10#	650 (1 litre)	699.6*		1.076	0.929
sum of top 3 fraction		168.0	160 (250ml)	1.050	0.952
sum of top 4 fraction		270.6	270 (500ml)	1.002	0.998
All the material		970.2	850 (1 litre)	1.142	0.876
All after one "tamp"		970.2	800 (1 litre)	1.214	0.824
All after second "tamp"		970.2	750 (1 litre)	1.294	0.773

The data in this table was collected during the sieving procedure for Table 2, for the fractions above 10 micron (#). The entire sample material for everything below 10 micron was recombined and reduced to a common state, then mixed in a tumbling "cube" - see text.

* This is the weight before sieving losses of 4.536 g and any other adventitious handling losses not recorded.

** This is the vessel volume used to determine the given value and was varied to give the best estimate of gross sample volume.

A collection of British Standard sieves was available but not necessarily in one of the approved size sequences e.g. root 2 (Zenz & Othmer 1960). The sizes used approximate to such a series. Equally, no standard enclosed automatic shaker was available and so sieving was carried out manually, with as uniform an approach as any experienced worker might achieve. This did have the advantage that the behaviour of the material could be inspected but ran the risk of airborne losses being magnified. This was guarded against by brushing down a large area of the surrounding work surface and weighing the material collected. The same was done for the large collecting tray used below the sieve array. This also checked the retention of fines by electrostatic force on the plastic surfaces involved. For those familiar with the maximum permitted industrial level of 10mgm^{-3} of a "nuisance" dust in the UK, then it will be appreciated that such a situation is a veritable

Table 2. Sieving results for the “gross” soil

Sample	D % in fr.	C % in fr.	B % in fr.	A % in fr.		% total *	% <10# (**)
> 8mm						7.6	
>5.6mm						4.5	
> 4mm						5.2	
> 10#						10.6	
>22#	8.5	10.4	11.2	11.0		7.3	10.1
>44#	7.8	13.2	8.0	5.5		7.0	9.7
>85#	15.0	13.9	15.1	15.6		10.5	14.6
>130#	16.8	18.7	18.9	44.7		13.0	18.0
>200#	8.7	13.2	11.7	2.8		8.1	11.2
>300#	30.8	21.4	25.9	12.4		18.5	25.7
<300#	12.7	9.1	10.9	8.6		7.6	10.6
% loss during sieving	8.7	8.0	8.6	5.6			
sample wt. (g)	13.38	13.75	13.92	14.76		970.2	968.8

* These values are computed from the total relevant sample weights using the percentages from the next column.

** These values are the averages for the results for samples D,C,B only because the result for A appears atypical. They are computed based on the final weights after sieving losses and applied to the total sample before sieving losses, assuming all fractions dried out uniformly.

Table 3. Sieving results for hill-wash material..

Sample	D % in fr.	B % in fr.	F % in fr.	C % in fr.		average % in fr.	% <10# (for fill Table 1
> 10#	1.64	2.20	2.14	0.59		1.5	**
>22#	4.70	2.86	3.66	2.66		3.8	10.1
>44#	5.11	6.03	4.39	4.89		5.0	9.7
>85#	9.75	8.71	9.28	9.00		9.2	14.6
>130#	11.68	10.48	14.10	12.16		12.1	18.0
>200#	10.03	3.94	4.79	4.62		5.9	11.2
>300#	8.30	6.97	9.71	10.40		9.5	25.7
<300#	40.49	55.71	51.62	55.75		52.9	10.9
% loss during sieving	10.6	N/A*	10.4	9.2		9.8	8.6
sample wt. (g)	12.19	N/A*	14.15	12.90		13.08*	13.95

* One weighing was not recorded. The average weight recovered for all four samples was 11.72g, however, and for this sample was 12.46g. Based on the average recovery of the other three samples and the recovered weight for this sample, this gives an indicative initial weight of 13.7 g, well within the range of all the sample sizes used for the analyses of the materials for both Table 2 and Table 3.

** The two materials are so markedly different, that the differences in the proportions within these sizes does not require adjustment, since 98.6% of the hill wash is below 10#.

Table 4. Flint contents of selected fractions from the “gross” soil.

	Number of pieces				Weight of pieces			
Size fraction	total	flint	chalk	chalk (%)	total	flint	chalk	chalk (%)
>8 mm	78	15 *	61 **	80.2	73.31	21.90	51.38	70.1
>5.6 mm	185	40	145	78.5	43.86	10.22	28.14	76.7
>4 mm	403	58	365	85.6	50.60	6.44	44.16	87.3
> 10 #	too fine				102.09			
< 200 #	too fine							100 ++
total					695.64			

The data in this table was collected during the sieving procedure for Table 2, for fractions above 10#.

* one large piece : 25 mm long axis

** 2 large pieces : 25 mm long axis

++ Visually, all the sample dissolved in hydrochloric acid. Any residue of undissolved flint that may have been present was not quantitatively meaningful.

"dust cloud". Since the room air showed no clear visible sign of such fine dust, during sieving, it may be assumed that the dispersed dust level was very much below this.

The "losses" per sample that could arise from these three sources were no more than 0.3 - 0.5g, substantially less than any changes evidenced in the results in Tables 2 and 3. It is reasonable to suppose that much of the recorded loss was therefore due to drying of the very fine materials during sieving, since it is not possible to "crumble" agglomerated fines, when bone dry, without serious risk of size reduction. The samples tested had accordingly only been dried in the laboratory air, on trays.

Table 2 gives the size results for the “gross” soil and shows the presence of a substantial proportion of large to small "stones", some of which are chalk and others flint in origin (Table 4 and later discussion). In order to compare the finer material in this soil with the corresponding size range material in the second material, the hill-wash, the data for this material has also been computed on a "stone-free" basis for the over 22 mesh material and smaller. This modified data is given in both Tables 2 and 3, so that various comparisons may be made without too much cross-reference.

Table 3 shows that the hill-wash material is substantially finer than the fines in the “gross” soil with more than 50% of the material being below 300 mesh, i.e. less than 50 microns. Size distributions do not naturally truncate suddenly and there was and is every reason to suppose that a large part of this small fraction is chalk-clay i.e. 2µm and smaller. This was checked qualitatively in two ways. Some of the sub 300 mesh material was wetted and rolled between thumb and forefinger. It was plastic and mouldable just as with a clay. Next some of the material was measured out and dispersed in water in a beaker. After half an hour, only rather more than half had settled (by volume, by eye), equally typical of a clay.

It is most likely that the fine material of the hill-wash represents the slow outwash of fines from the topsoil of the surrounding slopes, since the Ancient Farm at Bascomb is situated on the lower slope of a steep valley which has been farmed since Bronze Age times.

It is of some general relevance to the origin of soils, to include the impact of ploughing, a universally common practice, on top of the general geological environment and weathering, in particular. In the context of this presentation, it is also a useful insight to compare ploughing with that of industrial size reduction processes, such as mechanical grinding.

Ploughing progressively abrades soil particles and deeper ploughing, especially on chalk, breaks up subsoil "rock" to rejuvenate the supply of "stones" (large pieces). It is a slow repetitive process taking place over centuries, unlike the rapid, efficient and deliberate practice of an industrial process. To ploughing must be added the effects of weathering in creating changes to the range of particle sizes.

Figure 3 gives an indication as to how the size distribution of a particle assemblage changes as mechanical grinding progressively produces a finer and finer material.

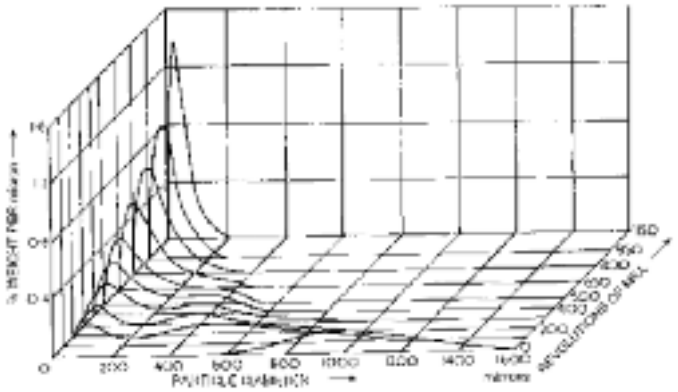


Figure 3. Size change with continued grinding of the same mix.

The point to note is the progressive diminution of the "hump" in the foreground (at 0 revolutions, before mixing) combined with a shift down the size range. This hump can be seen to persist as the amount of finer material increases, giving a clearly bimodal distribution until grinding is essentially complete.

Inspection of the far right hand column in Table 3, as taken from Table 2, shows a bimodality centred on the above 130 mesh and the above 300 mesh sizes, which may represent just such a process of degradation by ploughing and weathering. The “third” modality above 10 mesh (Table 2) may well represent the introduction of freshly generated larger material from deep ploughing of the chalk subsoil, suggesting the possible presence of a triple peak distribution.

This is supported to a degree by the data in Table 4, where there is reasonable evidence to suggest that the chalk is degraded to a greater extent than the flint. Chalk is deposited as microfine particles and then agglomerates on the sea bed, with a measure of cementation and/or recrystallisation, depending on the circumstances at the time of deposit and subsequent history, once raised and subject to soil water percolation. Thus weathering, in particular, may lead to very fine material being regenerated readily from chalk. Flint on the other hand is essentially a brittle amorphous crystalline substance and reduction to the finest material by ploughing, which is essentially low energy, is unlikely, even over

a long time scale. Equally, in low frost conditions, such as here in Southern England, it is quite unlikely for flint to generate clay-sized fines. This interpretation is consistent with the apparent total solubility in hydrochloric acid of the clay-sized fraction.

Returning to the more general geological context of the results for industrial grinding, there are two particularly clear-cut environments likely to parallel the given behaviour quite closely. One is the interface between any solid surface and a glacier, the other is in water rolling of stones / rocks / cobbles on beaches or in rivers.

The characteristic green-blue sheen of the water flowing out from glaciers and sometimes forming lakes is due to the suspension of micro-fines (clay-sized particles) produced by abrasion and carried away at lower flow rates leaving the grosser particulates behind until flood conditions occur. This approximates to the action of edge-runner mills such as may be seen in cement works for preparing the chalk / limestone or as may be used for making cosmetic products. Such mills are run most efficiently by periodically removing the fines which buffer the larger particles from fine grinding.

The beach process is akin to that of a ball mill, where large spherical grinding media are used to pulverise softer materials, such as cement clinker. This is the reverse of the polishing effect familiar to those interested in lapidary, where a fine hard material such as corundum is used to abrade the surface of the relatively softer semi-precious stones or whatever.

So, all that you learn about hardness in mineralogy is, after all, relevant to more general geological processes! Remember, it is relative hardness that dictates the resulting effect.

Review

This article has sought to introduce students to information and mechanisms, from a field of study not widely familiar to geologists, but which can be applied to a range of geological settings. Much of it is applicable, also, in engineering geology. The elements relating to soil will apply to a wide range of environmental situations, including restoration of contaminated sites.

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Book review

Uncertain Science … Uncertain World, by Henry N Pollack, 2003, Cambridge University Press, 243pp, £18.95 (hardback) ISBN 0521781884.

This book covers many subject areas in a well written, comprehensible manner. It is not high-tech and does not bring in too many specialist words. The author has a background in Earth Science, with research interests in the Earth's internal heat. The book covers these thematic perspectives:

- Uncertainty is always with us.
- Because uncertainty never disappears, decisions must be made in the absence of uncertainty.
- Predicting the future is a perilous business.
- Uncertainty is a stimulus for creativity

Topics covered include:

- Greenhouse gases and global climate change
- Earthquake prediction ('the next one will come when it comes')
- Inaccuracy in measurement e.g. the 2000 Florida US Presidential election count (and recounts)
- Bore hole temperatures
- Bioterrorism (anthrax spores in US mail)
- FMD in UK in 2001
- Helio- or geocentric cosmos

Scientists acknowledge that they do not know everything about a complex natural phenomenon, which the public may translate as the scientists do not know anything about the subject. This leads to loss of public credibility in the capabilities of scientists.

Early in the book, the author notes the wide conflict between science and personal belief: The Book of Genesis gives the creation of the universe and its contents in 6 days. Geologists and biologists claim that not every life form was present at the birth of the Earth. Therefore, if the Book of Genesis is correct, modern geology and biology must be wrong.

An example given was the knowledge gained from an inadvertent 'experiment'. Some containers of athletics shoes on a ship in rough North Pacific seas fell overboard, broke open and about 80000 shoes were let into the sea. They floated and were swept along by currents to North American landmasses. Oceanographers used the observations to understand the currents and eddys (this has been repeated twice since with coloured bath toys).

The author notes that historical sciences such as archaeology, geology and astronomy are uncertain sciences. Scientists try to recreate situations and make hypotheses, based on incomplete information.

Some 'what if' scenarios are included: oil running out, utility companies simulating power failures and the knock-on effects on populations (usually via computer models)

The book makes undemanding reading. It does not dwell on topics, nor go into great depth. It takes serious matters – matters which are of great importance to certain groups of people – and covers them in a straightforward manner, so enabling the reader to make their own decisions from their own perspectives.

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Clues from the Landscape

Gladys Dinnacombe

I travel by train regularly along a specific route from Kettering in Northamptonshire to a small place called Alsager on the Staffordshire - Cheshire border. Travelling by train gives a different view of the countryside as well as often giving views of the local geology in railway cuttings. But there are many other clues to the underlying geology: hills, lakes, the type of crops and hedgerow flowers and even the type of animals in the fields.

We can become so interested in studying rock faces and doing chemical research in laboratories that we forget all the clues in the landscape which surrounds us. Northamptonshire is a county of rolling hills and the area is mainly rural. Many fields show the old ridge and furrow patterns indicative of the way our ancestors farmed. But why does this county have these rolling hills?

The Middle Jurassic sediments form a gently undulating plateau and the Northamptonshire 'uplands' have a structure similar to that of the Cotswold area with a height of no more than 150m. These 'uplands' are dissected by rivers such as the Nene. The stone here has been quarried from Medieval times for use in building and more recently the ironstone was removed for use in making steel. The soil is brown or orange and is a clue to the ironstone and sediments beneath the surface. Where the ironstone has been removed the fields are generally around 3m lower than the road and this can be seen in places from the train. The fields are used for mixed farming in this area as the Jurassic formations can give rise to a variety of soil types within a very small area. The heavier soils and the flood plains are left as grassland as the soil is too heavy for crops of any kind. But a little further to the north and east, the Lias provides soils which are suitable for root crops and many small woods of ash, oak and hazel as well as land suitable for sheep and cattle grazing.

Figure 1. Ironstone outcrop (well - what do you expect when taken from a train!)

One very good outcrop showing the local strata can only be seen from the train. It is about 2m high and shows a deep band of ironstone jutting out from the softer sediments (Figure 1). It is situated between the main railway line to Leicester and the branch line to Corby (freight only on this line!) and can only be seen from the main line. Over the last couple of years I have noticed erosion at this site but as yet do not know how it would be possible to make it a protected site as it sits on Rail Track owned land.

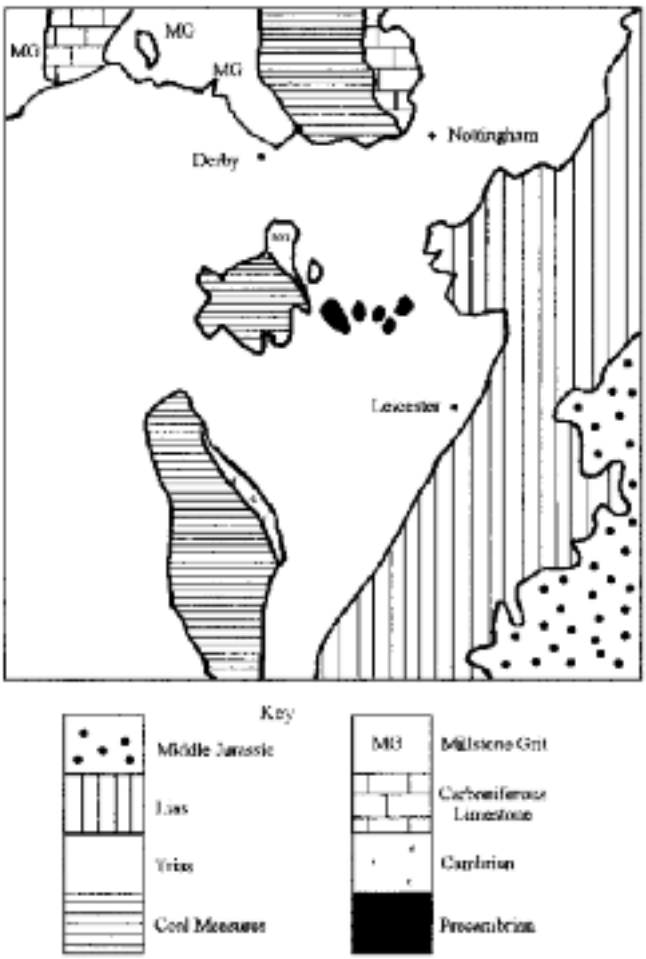

Figure 2. Sketch map to show the geology of the East Midlands area.

As you travel northwards to Leicester, the rolling hills disappear and the land becomes flatter. The crops in the fields change too and some of the fields are rough pasture, almost scrubland. At one point near the village of Kibworth Beacham, there are obvious excavations in one field, possibly for sand or gravel. Here we have moved on to the Middle Lias which forms clay vales with minor escarpments and plateaux (Figure 2).

North of Leicester, once the town has been left behind, the landscape changes again. The soil is often reddish from the thick Triassic beds and small hills can be seen on the horizon both on the left and right. The Keuper sandstones occur in thin beds among the marls and form sharp escarpments with steep or alternately convex and concave faces. These fall steeply to the west and gently to the east into the Trent Valley. The train passes through a large brickmaking complex, where freight trains loaded with bricks wait patiently in the sidings. Here, in the north Midlands, are Coal Measures with their associated iron ores and fire clays, sandstones and clays. The sandy areas are more elevated with drier soils and a different vegetation, heathland and coniferous woods.

To the west as you travel north, the small hills are part of Charnwood Forest, the isolated outcrops in the Precambrian which are surrounded by Triassic beds and Drift (Figure 2). Charnwood

Forest is about 6 miles north-west of Leicester and the craggy summits of bare rock can easily be seen as the train journeys onwards. The rocky summits are surrounded with bracken and the slopes wooded. The hills are 250 - 275m high and are quite prominent. The Precambrian rocks are of igneous origin consisting of volcanic lavas with tuffs and agglomerates and are some of the oldest rocks in England. They have been quarried for road stones after being exposed by the erosion of the red marls around them. The red marl formed under desert conditions but was then buried by the Lias and later rocks. All this was uplifted and then later eroded by rivers and the atmosphere bringing us to the landscape we now see. The highest hill, Fardon Hill, is 275m above sea level. The soil in general is loamy and used for pasture for sheep and cattle for which Leicestershire was famous at one time.

The small hills on the right which were seen soon after leaving Leicester are formed by the Mountsorrel granodiorite and surrounded by low-lying Triassic terrain.

After Loughborough, the train enters the Trent Valley and its many power stations loom on the horizon. The Trent is wide here, surrounded by the low-lying land of its flood plain. The towns of Derby and Leicester are both built on tributaries of the river Trent on the edge of a wide area of low country which is subject to extensive flooding. Both towns are built on red marls. The soil is mainly alluvial and is very productive agriculturally. The power stations on the Trent were situated there because of the local coal and the availability of water for cooling. The river meanders in broad curves and flows slowly widening its valley and building up the alluvial plain. Within the flood plain the surface of the alluvium is mainly flat but there are minor humps which cause some parts to be less flooded than others. Some of these raised parts are due to sediment deposited in the floods but others are man-made to strengthen the land and protect it from the floods. Gravel terraces are sometimes seen when the river level is low and these represent earlier flood plains.

Figure 3. Tutbury Castle built on a hill of red marl and alabaster rock; photograph taken from the train.

From Derby the railway line travels through an area of low-lying land some of which is part of the Trent Valley and which is often flooded as it is quite near the main river. Dairy farms abound as pasture is readily available while potatoes and wheat are also grown in this rich soil. At Tutbury the castle sits prominently on a hill and other small hills can be seen (Figure 3). Tutbury was originally the site of an Iron Age hill fort and the current castle sits on a hill formed of red marl and alabaster rock. There is a steep cliff on the north-west side and the River Dove on the north-east forms a natural defence. The original Norman castle was of the motte and bailey design but after falling into disrepair it was restored around 1270 - 1313 using sandstone from the local quarry in Winshill. It was rebuilt several times and more buildings added using stone from Repton as well as alabaster from Faulds and more stone from Winshill. Some time between 1681 and 1864 a folly/ruin was built and the castle became a tourist attraction as early as 1847. Now it is used for medieval banquets and re-enactment battles. There used to be a gypsum mine at Faulds from which the alabaster stone was obtained. In 1894 there were also three gypsum mines in the area. The rock was mined, sorted and then transported to a mill where it was made into potter's plaster, Keenes cement and also blocks for building. Alabaster was used in the building of a mansion in New York, each block cut by hand, loaded and then transported to the docks using a horse and cart. Some blocks weighed up to 15 tons. The gypsum mining industry is at least 1000 years old. Blocks of gypsum and decorative stones can be found in Tutbury Church and also in the foundations of the castle. The mine in Faulds is now owned by British Gypsum who still manufacture plaster for the building industry.

Gypsum is a naturally occurring mineral, created by the evaporation of sea water which contains about 3% gypsum. The chemical formula is $CaSO_4\ 2H_2O$. Massive gypsum can occur naturally and is then known as alabaster. The name alabaster is derived from Alabastron, a town in Egypt, where alabaster is also found.

Plaster such as Plaster of Paris, casting plaster and dental plaster, are all made from gypsum. The gypsum is heated to about 150°C, to drive off some of the water, in order to form the plasters named above. If heated to higher temperatures, all the water can be driven off and during the 19th and early 20th centuries, this was done to form plasters such as Keenes Cement and Parian Cement. These plasters set in a few hours and can be highly polished.

As the train nears Uttoxeter it crosses the river Dove which rises at Dove Head on the Buxton to Leek road and flows south-east,

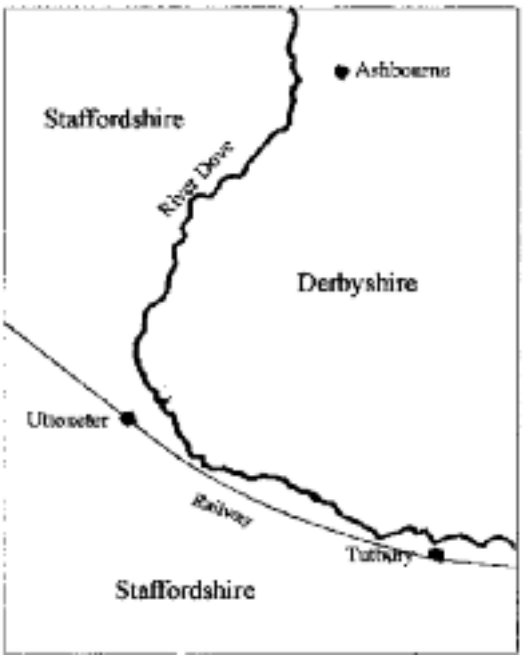

Figure 4. Sketch map to show the river boundary between Staffordshire and Derbyshire.

forming the county boundary between Staffordshire and Derbyshire (Figure 4). It joins the river Trent to the north east of Burton on Trent. The train then travels over an area with light sandy soils formed by the Lower Trias. This area is generally used for grazing but some crops, mainly grain can be seen. The land is generally quite fertile and Uttoxeter is known for the longevity of its inhabitants.

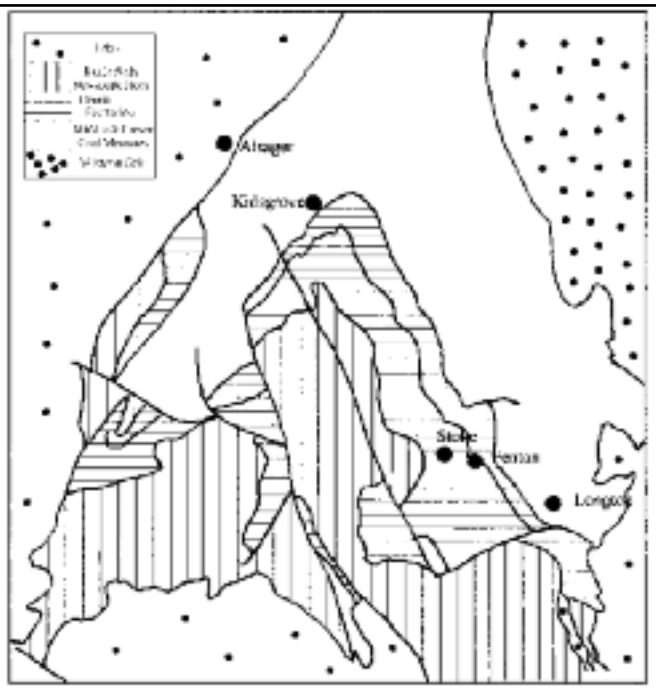

Figure 5. Sketch map of the geology of the area around Stoke-on-Trent.

At Stoke-on-Trent, there is obviously a lot of industry based on the underlying geology (Figure 5). The main industry used to be pottery with coal mining running a close second, but both are now in decline. The pottery industry, potbanks as they were called, grew very quickly from the abundance of local materials, such as the various clays and also coal used for firing the kilns, although now much of the china clay is imported from abroad. The Potteries area consists of six towns: Stoke, Tunstall, Burslem, Hanley, Fenton and Longton and the railway line passes through or near each one of these. These towns were originally small hamlets of Anglo-Saxon origin. The original subsistence farming economy was supplemented by the making of pottery from the local clay and the pottery industry goes back to the 14th century. The first factory for manufacturing fine pottery was established in 1693 by John Philip Elers, a Dutchman. By 1750 butter pots were well established with salt from the Cheshire Plain being used in the glazing process. These were made specifically for the dairy men using the market at Uttoxeter. The red clays of the Etruria Marl were used for special types of ware and the lighter Peacock Marls also added interest and excitement to the fast-growing industry. Old quarries can be seen from the train, one on the right-hand side as you enter Stoke station and one on the left about one mile after leaving the station. The first quarry is no longer used and appears to be of sandstone from its colour (Coal Measures are here but this quarry could have been worked for its clay). The second quarry is a marl quarry and is still working providing the clay for bricks and tiles made in this area. Also still standing, some now used as museums, are the bottle ovens or kilns, so called because of their shape (Figure 6).

Figure 6. Sketch of bottle ovens (with permission from Jane Clarke.©).

The North Staffordshire coalfield stands on the watershed between the River Trent and the River Mersey. The pottery towns were built on low hills which are geologically a part of the Pennine foothills. The escarpment formed by the Bunter beds divides good farming land on the Keuper Marl in the south and the poorer soils of the coalfield to the north. The Keele sandstones are part of the Upper Coal Measures and form a red soil as well as providing building stone.

The six pottery towns straddle the junction of the marls and coals of the Middle Coal Measures and the spoil hills are still obvious even though they have been landscaped. The spoil heaps are from the pottery industry as well as coal mining. The coalfield covers an area of about 250square miles and is a syncline plunging to south-south-west. In the west, it is thrown down by the Red Rock fault complex beneath the Triassic of the Cheshire Plain (Figure 7).

The Etruria Marl forms a distinctive group, thinning gradually from 305m to 213-244m and has large-scale rhythmic sedimentation apparent throughout.

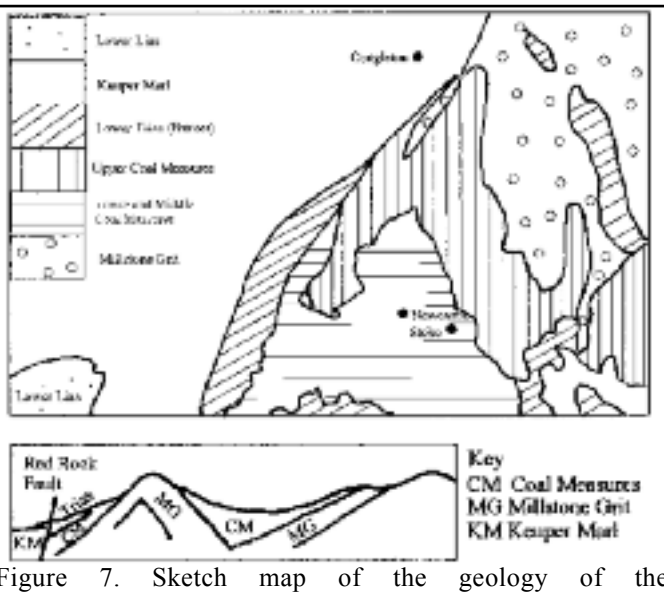

Figure 7. Sketch map of the geology of the Staffordshire/Cheshire border area and a section to show Red Rock Fault and the folds of the Staffordshire Coalfield.

To return to the first pottery town entered by the railway, Longton, the road running from Uttoxeter to Longton is an ancient route used by the Romans. It later became a turnpike road under the Turnpike Act of 1759. Other roads in the area have similar origins and these helped the growth of the pottery industry. The railway itself was opened in 1848 further enhancing industrial growth. As the train moves along on its journey we pass an almost derelict building on the right with the name British Steel on its side. Here used to be the steel works known as Shelton Bar. I remember as a child watching the sky light up when the furnace doors were opened and I remember hearing the huge roar. It has a beauty all of its own, this industrial landscape! The train now passes by other overgrown quarries, generally clay pits which provided clay for brickmaking. On the left the Newcastle-under-Lyme Group forms a prominent escarpment and the basal limestone can be seen at times capping the marl pits. The canal is also seen at times from the train and this was used to transport coal and clay. After the Harecastle tunnel, a ridge of land can be seen on the right, topped by a folly known as Mow Cop Castle. The outcrop on which the folly is built is of Millstone Grit. The Red Rock fault divides the Cheshire Plain from the Carboniferous. The Carboniferous here has a striking relief with north-south folds and the different beds with different thicknesses (Figure 7).

There are other hills here too but, to the left, the Cheshire Plain can be seen stretching far into the distance and the soil is red again due to the presence of hematite. This is rich pastoral lowland with hillocks and shallow peat-filled hollows as well as glacial sands and modern alluvia; a contrast to the bleak moorlands and long gentle slopes of the coalfield area! The Cheshire Plain is mainly boulder clay and laminated clay with deltaic sands. And so I reach my destination and alight from the train which moves off along a very straight line into the distance. I have travelled backwards in time from the Jurassic to the Carboniferous and then forwards to the Triassic!

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Book reviews

Snowball Earth: The Story of the Great Global Catastrophe that Spawned Life as we know it by Gabrielle Walker, 2003, Bloomsbury Publishing, 269pp, £16.99 (hardback) ISBN 074756051X.

As soon as I read the review of Snowball Earth which featured in the Science section of a recent Daily Telegraph, I knew that I had to buy this book immediately. The reason for this was because I had been intrigued by an article in the January 2000 Scientific American entitled 'Snowball Earth' by Paul F Hoffman and Daniel P Schrag, both at Harvard University, who posited that the Earth had suffered as many as four complete 'freeze overs', each of which lasted some 100s of millions of years, down to Equatorial latitudes between 750 and 580 million years ago.

This eminently readable book by Gabrielle Walker traces the origins of this radical theory from its many and various sources in a manner which gives a personal insight into the personalities of the geologists involved. It also homes in on their scientific approach to tacking problems and the manner in which the believers and non-believers of the Snowball Earth theory clashed during the cut and thrust of the scientific debate, and at times very personal antagonism, which seems to form the basis of the essential ritual of a theory becoming accepted or rejected by your peers.

The book revolves around the main character Paul Hoffman and his almost messianic quest to prove his Snowball theory against the tide of established thinking. The story travels, with the author often to the fore, from stromatolites in Western Australia to Precambrian rocks in the Canadian Arctic. The story continues with a 'mysterious' red stripe of glacial boulder clays in Svalbard, Norway and associated rock magnetism which indicate a palaeolatitude near the Equator, "dropstones" of the Namibian deserts and puzzling carbon-12 and -13 isotope ratios in its carbonate rocks above and below the Snowball glacial deposit 'event' and associated crystal fans in the "cap" carbonates.

In essence, this is a detective story told with a bold and flourishing style that should appeal to everyone with an interest in the Earth Sciences. I look forward to a more specialist treatise being published in the near future but, as research in this subject is at present generally only available in research papers, this may be some time in the future.

Tony Marter, continuing Earth Science student

Perilous Planet Earth: Catastrophes and Catastrophism through the Ages by Trevor Palmer, 2003, Cambridge University Press, 521pp, £45.00 hardback ISBN 0521819288

This is a very thorough, detailed and up to date book. It covers all aspects of the history of catastrophism from the myths of pre-history through to its decline in the nineteenth century with the introduction of gradualism through the ideas of such as Lyell and Darwin. It then moves into modern times with the revival of catastrophism. It looks at the conflict between the two camps which was most apparent in the nineteenth century with the introduction of gradualism and which still continues to a lesser degree even today. It covers many aspects of science from geology, evolution and astronomy through to history and social anthropology. It looks at how catastrophic events have influenced life on earth and argues that if we understand what has happened we may be in a better position to act if faced with such threats in the future.

If I didn't have to read this book I think I may have given up in the first part as I found some of the extensive detail a bit tedious, especially in areas where my background knowledge was a bit weak. However I'm glad I persevered as there were some interesting discussions and ideas. The last part of the book deals with the revival of catastrophism in modern times, it discusses mass extinctions, with reference to the K-T boundary, comet and asteroid strikes and Ice Ages and their effects on civilisations. I found this very interesting and there were other parts I also enjoyed.

As I have said, the book is very detailed and right up to date though in some areas it may date very quickly. It is well referenced with nearly a third given over to references and the index. For anyone studying the subject this is a 'must have' reference book, it brings many ideas and theories together and then shows you where to go for more information. I don't think there's much it doesn't cover. As light reading it might be better to start with something a bit more general, especially as this is not a cheap book.

Rosemary Vidler, BSc Hons (Open)

Doom-Day with Diatomite: of one obscure morning 8,300,000 years ago

Rob Heslop

A bleak winter in the Rhone valley. The Lyon Mountains are snow covered, as is the nearby Pilat National Park. And the Ardeche is frosty. Nevertheless, tomorrow we are off to La Voulte Palaeontological beds; that is 30-odd screaming youngsters, three adventurous parents, Professor Paul De-job, and myself.

By seven thirty we had already counted the kiddies, boarded the bus, left the pick up point at Communay and were on the motorway. *"Bonjour monsieur le chauffeur!"* the kids sang out under professor De-job's command. Speeding down the *autoroute de soleil*, we admired the magnificent mountain views of *Le Crest de L'oillion*,the *Crest de Perdrix* and other snowy summits of *La Pilat Parc*.

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La Voulte is to be found at the Ardeche region, or *departement*, built upon the west bank of the Rhone and shadowed by mountains which rise steeply to the west of this medieval *Bourg*. Forming the village centre is an ancient castle built upon high crags; it is at the base of these crags that *La Voulte Palèontological Musee* is to be found.

We all left the bus and together we gathered and directed, two by two, the long line of woolly hatted, bulky annoraked, mitten wearing, rucksack carrying, multi-coloured, cheerful, happy kiddies along the narrow busy streets and arrived at the museum.

Bernard Riou greeted us all with an enormous, genuine smile. The young palaeontologist intended to spend his entire day with us and he was only too pleased to do so. But first, a short visit around his incredible fossil museum. Once inside the museum, the large group is split into two.

Paul takes one group upstairs, accompanied by Bernard's young palaeontological student, to watch an education video concerning the 'History Of Life'. The second group, including myself, remains on the ground floor with Bernard for a privileged guided tour through the exhibits of this small, self-run museum. Bernard talks the children through time, explaining the beginnings of life and evolution. Using his own fossils, he teaches simplified geological processes. The kids are fascinated!

Exhibits in this collection are rare and varied and mostly originate from within the surrounding vicinity of La Voulte: inferring to the many different stratas which are locked within the local landscape. Twenty five years of hard work, deduction, patience and skill lie before us neatly displayed on glass shelves and inside wooden cabinets. One surprising fact about the local finds from La Voulte is that there are so many different sedimentary strata to be found in one area.

The Geology and the museum

The Ardeche *departement* is arid and mountainous; it forms the easterly part of the picturesque Massif-Central. The majority of the surrounding mountains are metamorphic and basaltic, formed mostly of chlorite and sericite schists. There is an important fault line, spreading east to west, and is appropriately called *La Faille De La Voulte*.

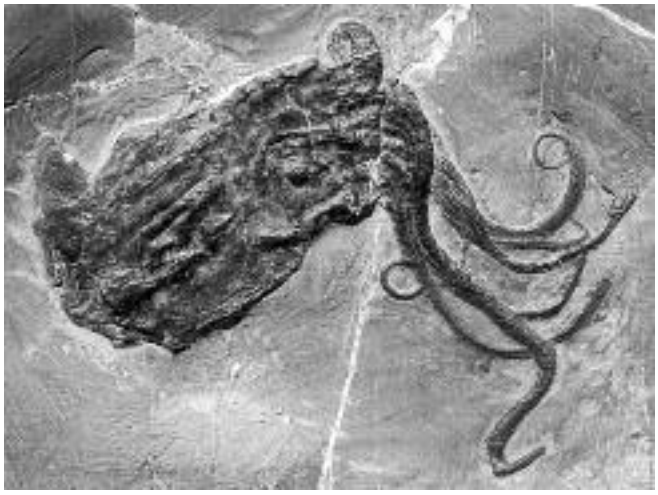

Figure 1. *Proteroctopus ribeti* from the Jurassic-Callovian ©Bernard Riou.

During the Palaeozoic Era (around 600 to 250Ma), the Ardeche *departement* was even more mountainous than today and could have been comparable to the Himalayas. Over a phenomenal time-span the mountain areas slowly eroded until, during the Triassic, they were reduced to small hills and flat-lands and eventually becoming partially submerged by the mid- Jurassic. Then, throughout the Tertiary (Palaeogene 65 to 50Ma) the lands re-emerged as the Massif Central heaved due to Alpine folding. It was through this 'recent' uplift that Triassic and Jurassic sediments re-surfaced and swelled. In some places inversion has occurred.

It was in 1843 that the first geological interpretations were given. J Fournet described La Voulte sites before the Jurassic limestone blocks could be quarried and extracted, ready for use in building railways and canals and to reinforce the banks of the river Rhone. The various Jurassic strata from these quarries have exposed masses of marine fossils: ammonites, bivalves, belemnites, reptile remains and sharks' teeth. But it is from the mid-Jurassic of Callovian (160Ma) that we find the most exquisite remains. As from the early eighties, Bernard (in collaboration with the Paris Natural History Museum, the Bochum Museum, Germany and with the University of Bristol, England) investigated these unusual sediments. The petrified grey muds in this sequence contain nodules which, in turn, contain perfectly preserved, 'mummified' fossils. Creatures such as soft-bodied, marine annelids, strange arthropods and a large assortment of crustaceans: shrimps, lobsters and crabs, some forms of which, now extinct, have never been discovered elsewhere, (*Kilianocaris, Clausia*, and the giant *Dollocaris*). The strata have also revealed many species of Cephalopods, the most extraordinary find to date being a 'mummified' octopus (*Proteroctopus ribeti*) 20cm long and 160Ma old; this is the oldest fossil of its kind ever to have been found (Figure 1). Petrified fossil fish and shark remains also count amongst the finds from the remarkable seams of the Callovian. Seen together these fossils evoke the magnificent blue of a shallow Jurassic sea. The waters teem with lively, enigmatic creatures; they fight,

breed and contend. Each has a part to play in a delicate, fragile system. Fantastic; this tiny instant of frozen Callovian life remains *in situ* and seems to boldly challenge a vast gulf of time.

The visit continues and we come to another outstanding local collection: that of the Upper Miocene strata (Messinian, 8Ma). These sediments are known as *diatomite*. The Messinian diatomite sites are to be found in the nearby quarries of Coiron. Diatomite is porous and is usually found heavy and gorged with water; hold a slab at arms length and H_2O trickles within seconds! Wet diatomite has a deep, shiny dark green colour; left aside to dry, it rapidly transforms to a surprising mat-chalk-white and from heavyweight it becomes a balsa-wood lightweight and can float on water!

Diatomite is a strange stone stuff indeed and is formed by a compact mass of micro algae debris named *Navicula*. (Diatomite is also known as Randanite or Bann Clay.)

During the Messinian algae-rich waters, muds, silts and sediments were to be found in, and around, large freshwater lakes. At this period the numerous lakes and rivers were hampered by constant volcanic activity. These areas were surrounded by pine and deciduous landscapes.

One can easily imagine that unstable land of the Coiron-Messinian. A regular spew of ash or lava from a disruptive volcano causes death; birds flee, mammals scatter in confusion, trees fall and small lakes are instantly filled by a hot lava flow. Land-life and lake-life are thrust into the cooling soft lake diatomite muds; each Messinian victim is entombed, preserved and held by time's fist .... The capricious mountain calms and, over a year or two, life timidly returns.

By coincidence, the quality of the preservation of the Coiron fossils is similar to that of the La Voulte fossils.

Figure 2. Bee

Messinian rabbits and rats, entombed, complete with fur; beetles, bees (Figure 2) and dragonflies, entire, with wings, legs and thin antennae; snakes, toads, fish! Pollen, twigs, bark, and leaves. There is even a tiny Miocene bird (Figure 3), vivid, with feather, beak, and eye!

Further in the museum we see two large boars (*Microstonyx*), captured upon a giant slab of diatomite and both held in a running position. Even more astounding, we stand before a primitive horse, *Hipparion* (Figure 4): enormous, the pregnant mare suffocated to death whilst sinking in boggy silts; the animal encountered Doom-Day inside the diatomite more than 8,300,000 years before. We find the creature's last agonizing moments of life daunting ...

The Great outdoors

After a midday packed lunch we join Bernard in the town carpark and the whole bunch of us board the bus and set off to visit *La Voulte* quarry.

Figure 3. Small unidentified bird from the Miocene-Messinien. ©Bernard Riou.

For security reasons, Bernard has organised several truck loads of different sediments to be stockpiled upon the quarry floors, away from the high and dangerous rock face. Piles of diatomite from the Coiron quarry have also been gathered, trucked and delivered. The majority of kids make a rush to the nearest heap of rocks and rummage through the Oxfordian dumps hunting for sharks' teeth.

Figure 4. *Hipparion* skull. ©Bernard Riou.

Joined by Paul, Bernard and a handful of eager kids, we set off toward a giant pile of green rock, sediment and stone; the diatomite.

With hammer, chisel and blades, the thick water-logged stone is easily split. We find fragments of leaf, twig and wood; the kids love it and there are regular cries of joy from the young discoverers, accompanied by a never-ending, *"S'il vous plait monsieur!..."* and as one lad finds a fossilized dragonfly's wing.

Aided by a youngster named Gilles, I worked a while upon a large slab and progressively cut it down. When it had been chopped to a more practical size, we split the dark green, wet diatomite neatly in two. As the stone spilt it oozed a sucking, peeling sound, and there placed right in the middle was a perfect, bright amber coloured sweet chestnut leaf, *Castanea sativa*! After being clasped in stone for over 8Ma, this Messinian jewel (Figure 5) is released into the surrounds of a new eon and from the freshly cut rock seeps an odour of pine; wizardry has spun the last remnants of a fossilized odour upon the new-scapes of an ever changing planet!

Figure 5. *Castanea sativa*; the stone secreted a pine odour. ©Bernard Riou.

It would seem, after today's winter visit, of ancient ammonite, octopus and hipparion, and after smelling the airs of the Messinian pines, that life can be so enchantingly strange.

Life, as one continuing entity, thrives upon every possible *endroit du globe*. As life stretches through time, then time stretches through distance and, if space and time are one, then life must somehow weave along, and perhaps together share a symbiotic harmony, upon a universal, cosmic scale.

Time is a common denominator; only through time can life creep through distance; and life, in all its various guises, may well have had enough time to have done so.

Perhaps time and space and life are just meant to be … and the smell of the Messinian-pine-woods of today is all but a coincidence.

Acknowledgements

Many thanks to Bernard Riou for expertise throughout this article and for the loan of the photos herein; thanks also to a fossil-crazy school teacher and friend, Paul De-job.

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Originally from Northumberland Rob left the UK at the age of 19 and has been in Lyon for 16 years or so. He lives with Anne, a musician and has three children, Laura, Kevin and baby Matty. He works as a postman. He loves the great outdoors, and spends much time 'exploring', painting landscapes, and writing short natural history articles. He reads a great deal on topics such as palaeontology, British prehistory, the French Gallo-Roman period, archaeology, botany, wilderness and landscape.He enjoys the new science of exobiology and generally all concerning the ongoing quest towards understanding that strange and enigmatic Life-spark!

[NB Rob has a follow-up article which appears on the OUGS Mainland Europe website at http://users.skynet.be.ougseurope/ under the heading "Hipparion Speak".]

Book review

An Introduction to Seismology, Earthquakes and Earth Structure by S Stein and M Wysession, 2003, Blackwell Publishing, 498pp, £34.95 (paperback) ISBN 0865420785.

Seismology is the study of earthquakes and associated phenomena, or the study of elastic waves propagating in the Earth. It has become the major tool for earthquake hazard assessment, hydrocarbon exploration and the peacekeeping role of nuclear test monitoring. This book was written for advanced undergraduates and beginning graduate students. The authors' goals being to interest students in the subject, convince them it is worth the effort required learning about it and helping them to do so.

Following a comprehensive introduction to wave propagation and seismology and society, the book takes the student through a year's worth of lesson material covering all aspects of seismology before exploring the use of seismograms as signals of processes acting in the earth. The final chapter introduces and discusses "inverse problems". An inverse problem is one where we know the result and have to determine the process that produced it. As an example, the classic inverse problem is that of finding the origin of an earthquake by using the arrival times of seismic waves at various stations. The book concludes with an appendix containing the mathematical and computational background. I found this appendix particularly useful as it reviews spherical geometry, matrix algebra and scientific programming amongst other subjects. Fortran is the programming language of choice because of its suitability for scientific programming, although other languages can be used.

Although the book is an advanced text and is heavy on the science and the mathematics, the authors' methodical approach and transition through the subject make it a suitable text with which to build on undergraduate studies. A further reading list at the end of each chapter provides additional material as required. Each chapter also includes a set of mathematical and computer problems. I was disappointed to find that the book provides "solutions to selected odd-numbered problems" only.

If you have found seismology and earth structure an interesting aspect of your earth science studies this book is a valuable next step, supporting the authors' contention that seismology should be part of the education of every solid earth scientist.

Mike Hermolle, BSc(Hons)NatSci(Open)

Clay Mineral Cements in Sandstones by Richard H Worden & Sadoon Morad (eds), Special Publication Number 34 of the International Association of Sedimentologists. Blackwell Publishing 2003. 509pp. £75 (paperback). ISBN 1405105879.

I have to say that I approached this book with some trepidation. It is a daunting prospect, 487 pages of text. However, having read it, there is plenty to gain from it, and I now know a lot more about clay minerals!

The book consists of 21 review papers written by sedimentologists worldwide. The first papers are wide-ranging, covering such subjects as evolution, diagenesis, cementation and paleoclimatic controls and much more all relating to clay minerals. The subsequent papers are more specific, dealing with case studies of chlorite, kaolinite, illite and glauconite.

The layout is well presented with numerous scanning electron microscope micrographs, facies diagrams and graphs. On the other hand there is a plethora of formulas and equations, which is quite beyond my comprehension.

Clays are an important group of minerals that destroy the permeability in sandstones, so are of the utmost interest to geologists involved in the extraction of hydrocarbons. This book would, therefore, be valuable for petroleum geologists, for sedimentologists, for geologists studying the formation of clay cement in sandstones. The book will also be of interest to geologists involved in paleoclimate studies and basin analysis.

In summary, this is a book for the specialists in their field and not recommended for the average OU student.

Ellinor Morgan BSc Hons (Open)

A field trip in Guatemala

John Lombard

Since retiring from the bank I have been in the habit of spending as much of the winter as possible in some warmer climate. A few years ago I completed course S260 with the Open University, and since then my trips abroad usually include an element of geological interest. In December 2001 I embarked on a tour through several Central American countries, a part of the world which is beginning to make a name for itself from the tourist perspective. There is a great deal to see and enjoy, tropical beaches, lost Mayan cities, rain-forest teeming with wild-life and, towering above all, there are the volcanoes.

It has been known for centuries that most volcanoes occur in volcanic arcs. It was only in the last half of the 20th century that the reason for this became clear. It is surprising to think that until very recently we had a better idea of what was happening in the interior of the distant stars than the internal processes of our home planet. It is now understood that great sheets of basalt emanate from the thousands of miles of mid-ocean ridges which wind their way around the planet. When the 7 or 8km thick basaltic plate converges on a plate of lighter continental crust it tends to underthrust it and become subducted. At some point during its descent into the mantle the basaltic plate, or slab, loses its volatiles and fluids. These pass upwards into the overlying mantle wedge. As the presence of fluids and volatiles has the effect of lowering the melting temperature, large amounts of magma may be generated. This magma will eventually find surface expression in a continuous chain of volcanoes or plutonic intrusions. The Andes mountains of South America are a classic example of mountain building as a result of modern-day Plate Tectonics.

A glance at the tectonic map of the Earth shows that in the Central American region, the oceanic crust, as represented by the Cocos

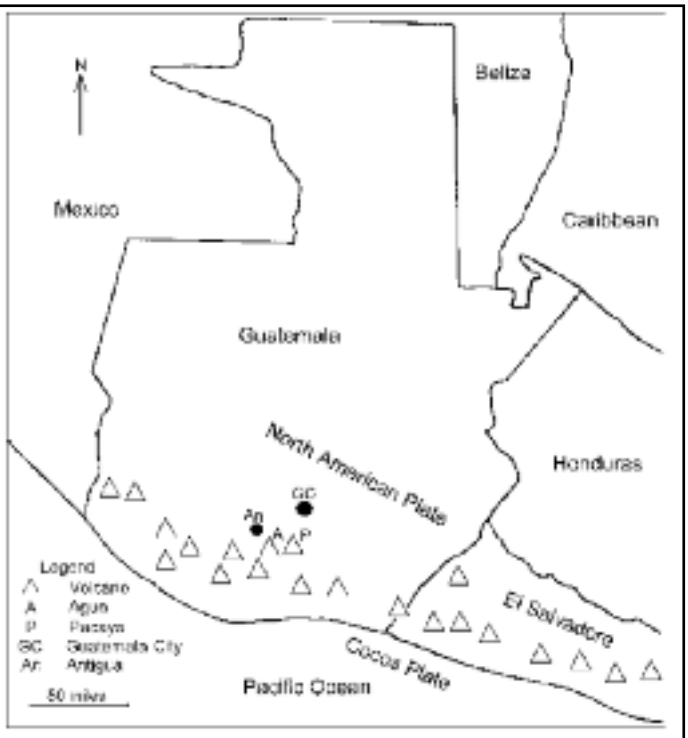

Figure 1. Sketch map of Guatemala and surrounding counties showing volcano range.

Figure 2. The 8000ft high volcano Pacaya, Guatemala.

Plate, is being subducted in a north-easterly direction beneath the Caribbean Plate. The rate of subduction of the Cocos Plate is about 8cm per annum (Gordon 1977). The modern volcanic arc occurs above the 100km contour of the Wadati-Benioff zone (Gordon 1977). Isotopic research shows that ignimbrite-style volcanism began some 31Ma ago in Honduras (Gordon 1977). The Caribbean-Cocos Plate boundary is seismically very active. This is due to the rapid convergence rate. Two great earthquakes, in 1854 and 1859, have been recorded off the Pacific coast of Guatemala near the triple junction of the Cocos, Caribbean and North American Plates (Gordon 1977). The chain of volcanoes which the subduction has given rise to, nowadays forms a great crescent stretching from Mexico to Panama (Figure 1). A number of these volcanoes are to be found in Guatemala and one of them, a volcano called Pacaya, was the object of a day's excursion for myself and a minibus load of fellow enthusiasts.

In order to get to Pacaya we first had to spend a few days in the city of Antigua, a place well worth describing. This city was the original colonial capital of Guatemala. Unlike many population centres in the region, Antigua was not built on an existing Indian settlement but was founded from scratch. It was intended to be a model city, its cobbled streets intersect at right angles and all the buildings are of the same height. The overall effect is of great order and regularity. To my eye it is very similar to Oaxaca in Mexico. The Colonial architecture of Antigua has changed very little over the centuries; many of the great front doors of the colonial mansions still retain the two door-knocker system. One knocker is at eye level and the other is ten feet off the ground so that callers on horseback would not have to dismount! As a capital city Antigua did not last long. In the 18th century it was severely damaged by an earthquake and Guatemala City became the capital instead.

Ever since my return from Central America I have been trying to gather as much scientific information about Pacaya as I can. One of my sources describes Pacaya as a "complex volcano", consisting of an older stratovolcano, domes, flows, tephra and the modern basaltic stratovolcano (Volcano world).

Most of the complex has formed in the past 23,000 years (Volcano world). Pacaya is situated some 14°N of the Equator

Figure 3. The last few hundred feet to the summit of Pacaya. Steam and gas is seeping from the mountain-side.

and at 91°W. The volcano is just over 8,300 feet high and is quite active (Figure 2). The last major eruption was in 1989 and there were extensive lava flows in 1990 and 1991. But nearly every year since then there has been further activity, either in the form of further eruptions, ash falls or degassing of $S0_2$. The latter was evident on the day of my visit.

The aforementioned minibus carried us nearly three quarters of the way to the summit, leaving us with a three hour climb up to the crater. The first two hours were easy enough. The journey was uphill of course, but we were shaded by the forest which covers the lower flanks of the mountain and the going underfoot was good. Once we cleared the tree-line however progress became harder. The last few hundred feet of the climb are the real difficulty. The volcanic cone (Figure 3) is little more than a huge unconsolidated heap of ash and clinker. It crumbles away under foot and even under one's hand. Also, of course, it is very steep. The net result is that for every three feet you climb, you are liable to slide back ten. This makes for very heavy going and the need for physical fitness was apparent to me well before I reached the top. However I had not come 10,000km or more in order to be beaten by mere topography so, by a combination of persistence and frequent rest stops to get some breath back, I finally managed to make it to the summit.

I have to say that, from a scenic point of view alone, the reward was well worth the effort. To both left and right other volcanoes receded into the distance. Far below, the green carpet of rain-forest stretched away in all directions. Even when supposedly quiet, the fiery heart of Pacaya is very much in evidence (the name Pacaya means "fiery mountain"). Gas and steam seep from cracks and crevices. Put your hand to the ground and you will be unable to keep it there for more than a moment because the heat flow is so high. At the crater itself every few minutes there is a ground shaking "Whoof" as a great gust of sulphurous-smelling gas is released.

I took away a small rock specimen from the crater rim when leaving. It appears to me to be a de-volatilised basalt. It has a pumice-like texture with many vesicles and is rich in sulphur.

I have been surfing the net in an effort to obtain information about the tectonic setting and the petrology of the Central American volcanic province in general and about Pacaya in particular. Much of the available information deals with isotopic ratios and trace elements and I will be referring to this type of information later (Cameron *et al.* 2002). In broad outline, however, it appears that Pacaya (and its nearby sister volcano, Agua) produce a suite of lavas which differ markedly from other volcanos in the region. This is despite the fact all these volcanoes appear to owe their existence to the same tectonic process, namely, the subduction of the Cocos Plate. Most Guatemalan volcanoes produce lavas of andesitic to dacitic composition. However, the lavas of Pacaya and Agua are basaltic and are richer in the minerals olivine and pyroxene while being relatively poorer in silica. This must have been a considerable conundrum for the geo-scientists to tackle. Why, if the inputs were the same, were the outputs so different? It must have taken a lot of field trips and a lot of laboratory work to reach a credible solution.

Students of S339 will be aware that "Magmas related by fractional crystallization will have trace elements that lie on a straight line when they are plotted on logarithmic graph paper" (S339 p28). In plain English, if a magma chamber is left undisturbed, it will cool and solidify. Fractional crystallization will ensure that there will be an evolutionary trend in the rocks thus produced. There will also be a (logarithmically speaking) *pro rata* trend in the trace element abundances. However, if the magma chamber has been disturbed, perhaps by an influx of fresh magma from below or by melting and entraining crustal rock, then this relationship will no longer hold. Thus the study of trace element abundances can shed much light on the volcanic history of a region. For example, it can show if neighbouring volcanoes are related, or it can show if two eruptions from the same volcano came from the same source.

Perhaps more central to the Pacaya/Agua problem is that of magnesium number. All volcanic rocks have this number and it is derived by comparing the amount of MgO in weight% in a rock sample to the weight% of FeO present. Basically all this means is that the greater the amount of MgO relative to FeO in a rock, the higher is its magnesium number. When mantle rock undergoes melting magnesium tends to enter into the early stages of crystallization thus the remaining melt will be depleted in magnesium relative to its parent rock, i.e. it will have a lower magnesium number. The magnesium number of a particular lava sample can be very useful in tracing its origin and history. A high magnesium number indicates a primitive magma, one that has come uncontaminated from the mantle. On the other hand, a low magnesium number indicates that the sample rock came from an evolved magma: one that had melted and crystallised a number of times in the past. Modern-day lavas from Pacaya have a high magnesium number compared to other volcanoes in the region (Cameron 2002). This could mean that Pacaya (and Agua) are deriving their magmas from a different source from the others; however, another set of ratios shows that this is not the case.

It was a matter of surprise to me to learn that something as relatively fragile as marine sediment can undergo the extremes of heat and pressure as a result of being subducted with a tectonic plate, survive for a long time stewing in a magma chamber, and yet leave its signature in the erupted lava. It can do this by imparting a high U/La ratio and a high Ba/Th ratio to the solidified lava (Cameron 2002). All Guatemalan volcanoes show these high ratios. This clearly indicates that they have all had an input of hemipelagic sediment and the only possible source is the subducting Cocos Plate. This supports the statement that "Basalts ... in Nicaragua, El Salvador and Guatemala are mainly derived from

slab-modified, depleted mantle characteristic of volcanic arcs" (Johnston & Thorkelson 1997). But this does not explain why Pacayan lavas are different.

The answer was found to lie in the tectonic setting. It turns out that both Pacaya and Agua are located on a graben bounded by a geological feature called the Jalpatagua Fault. In this locality the Earth's crust is undergoing extension in contrast to the region as a whole. As a result of this extension the crust in the Pacaya/Agua area is thinner than elsewhere in the region and this has a twofold effect on the magma which is produced.

1) In the Pacaya/Agua area, magma which ascends from the mantle wedge has only a thin cover of continental crust to penetrate. Consequently the magma becomes less contaminated by continental crust than is the case elsewhere in the region (Cameron 2002).

2) The thinning of the crust reduces pressure at depth. It is thought that this enables decompressive melting to occur at the top of the mantle wedge underlying Pacaya and Agua (Cameron 2002).

I like to think that the little piece of rock I took home as a souvenir is more representative of mantle peridotite than any specimen I could have obtained elsewhere during my trip to Central America.

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Author

John Lombard is a 59 year old retired bank official. He grew up and was educated in Gorey, Co Wexford. In 1962 he joined the National Bank (now Bank of Ireland) and worked in the branch network for most of his service. In 1982 he enrolled in the Open University and obtained a BA degree. He retired from the Bank in 1994 and resumed his studies with the Open University, completing a B.Sc. degree last year. Since retirement, John, who is unmarried, spends two or three months abroad each year, the more exotic the destination the better. He is a member of the Westwood Club and enjoys swimming and tennis. When not away from Ireland he lives in his apartment in Harold's Cross in Dublin. His present ambition is to obtain a named degree in Earth Sciences.

Book review

Krakatoa – The day the world exploded – 27th August 1883 by Simon Winchester, 2003, Viking, hardback ISBN 0670911267/ 0670914304, paperback ISBN 0670914282 price through BOL.com - £6.79 + £1 postage.

As might be expected from the title Winchester's book describes the events leading up to and following the explosion of Krakatoa on 27th August 1883, as chance would have it exactly 120 years before the date of me writing this report. Whilst "Krakatoa is reckoned to be only the 5th most explosive volcano in the earth's history", nearly 40,000 people were killed! It was the first time that "sophisticated human beings were on hand to see this volcano's convulsions, they were able to investigate the event and they were able to attempt to understand the processes that had caused such dreadful violence" (Winchester – Page 5). This was also the first major disaster to be reported by the newly installed telegraph system.

Winchester's description of events is much more than a geological sequence. In the 408 pages he takes the reader through the social, political and economical history of an area which became known as the Dutch East Indies – now Indonesia. He describes how the pepper and spice trade became the source of significant wealth and how the Dutch colonised Java and the surrounding area. One of Winchester's strengths is his great attention to detail. Detail that, at times, I found tended to be irritating and repetitive, but that is a personal opinion.

Winchester describes the "history" and processes of plate tectonics. For readers with limited geological knowledge it is an easy to understand the non-technical précis (I think!). For those whose knowledge is sketchy is serves as a useful refresher (I hope!). Those who know it by heart can skip over these parts! He also describes other scientific discoveries such as The Wallace Line and introduces a new (well new to me) perspective on some of the work more commonly attributed to Charles Darwin.

There is an abundance of graphic, sometimes harrowing, eye witness accounts of when Krakatoa erupted and the impact this had in other parts of the world. Also reports of the investigations which followed.

Finally Winchester outlines how the impact of the eruption contributed to the downfall of Dutch colonialism and fuelled the rise of Islamic fundamentalism. The fact that this was not published until 2003 meant that Winchester was able to quote from very recent, world events. I also drew parallels with the lecture by Professor Baillie at the Dublin Symposium. Members may recall he studies dendrochronology (tree rings) and also quoted how, in history, geological events had contributed to the fall of significantly powerful empires (OUGS Journal – Symposium edition 2001 Volume 22 (2)

There is also a mention of OUGS. No, sadly not our Society – the other OUGS – the Oxford University Geological Society!

Few books sufficiently capture my interest such that I read them cover to cover – but this was one did. I recommend it as an ideal companion for airport waiting and long flights. It is also a thoroughly enjoyable read.

Ron Whitfield

Yukon Gold

Gordon Bullard

Introduction

After 26 years of amateur prospecting for gold in the UK., which started with a chance find of a small gold nugget in the river Mawddach near Dolgellau, I finally realized that there probably was not a fortune to be made in the UK prospecting in placer gravels. So in 1993 I decided that the obvious place to go was where gold was still being found and mined. Of the various locations around the world that fitted the bill I finally decided upon Canada, as the cost of air travel was reasonable and the services regular. So after a lot of research I finally found myself flying over Hudson Bay *en route* to Vancouver. After an overnight stop in Vancouver and a further three-hour flight, I arrived in Whitehorse, the capital of the Yukon. Whitehorse is a bustling, typical frontier town of brick and wooden buildings located within a strict grid system of roads. The flight to Dawson City, current centre of gold mining activity in the Yukon and scenes of frenzied activity during the 1896-1899 goldrush, was made on an old Second World War vintage Dakota aeroplane. One side of the aircraft held a row of twin seats whilst the other side had cargo nets securing mailbags, crates of foodstuffs and assorted hardware for the miners. Dawson airport turned out to be two large huts in a field and approaching aircraft have to fly down a tight valley and then perform a sharp 90 degree turn just before landing, which made passengers hang on to their seats and the cargo nets strain to hold their contents secure. The road from the airfield to Dawson is about 6 miles long and for most of its way passes through a lunar landscape of dredger tailings which still, after some 50 years, are still unvegetated (Figure 1). At last I had arrived in Dawson and the prospecting could begin.

Figure 1. The Klondike River valley in the foreground with Bonanza Creek to the upper right-hand side. The dredger tailing trails can clearly be seen in the valley and to the mid-centre the remains of an hydraulic mine which used water monitors, can also be seen.

Geological Overview

The gold in the Dawson region originally came from rocks of igneous origin, which would have dated from the Cambrian or Silurian periods *c.*400Ma. I say originally, as these igneous sericite schists were eroded during the late Pliocene, generally leaving the heavy gold in stream and river gravels. This whole region was uplifted in a generally N/S direction, facilitating rapid erosion and tending to concentrate the gold on the underlying bedrock and in river gravels. The semi-arid climate in the region during the last ice age meant that there was little or no glaciation and, because of the continual extreme cold and resultant permafrost, erosion has been minimal: factors which helped to ensure that the gold remained *in situ*. The bedrock and gravels are now covered with soil and vegetation, which is permanently frozen.

The whole is topped with a further layer of soil and vegetation which in summer grows abundantly and supports a wide range of birds, insects and mammals. Gold deposits are found at the present day: in the beds of modern streams and rivers; in the beds of ancient streams; on raised benches and in modern water courses.

The Gold Rush (1896-1899)

As with most gold discoveries, the Yukon strike was made accidentally. Although small amounts of placer gold had been found in Alaska and along the Yukon River and its tributaries north of Dawson there had been nothing significant. That is, until three friends decided to investigate the Klondike River and its tributaries during their annual summer fishing expedition in 1896. Whilst hunting for game in Rabbit Creek one of the partners went to the creek to get water and observed bright reflections. The gold was lying thickly on the bedrock and was likened to cheese in a sandwich. The creek was renamed Bonanza Creek and the rest is history with the three discoverers and other claim holders arriving back in Portland a year later with no less than one ton of gold between them. The news stunned the world and the rush was on. Dawson, initially a summer native fish camp, had a population of 30,000 three years later. Needless to say when most of the stampeders arrived, all the good claims had been staked and most of them ended up labouring and finally going home as poor as when they arrived.

Original Mining Methods

During the summer months gold was extracted from the creek beds by panning the gravels and by using sluices with various kinds of riffles and other devices to trap the gold. However, most of the gold-bearing gravels were covered with permafrost, typically to a depth of anywhere between 10 to 30ft. Figure 2 shows a typical creek situation with the auriferous sand and gravel resting on bedrock. The permafrost is seen to centre and right and is topped by vegetation, the surface to bedrock depth here is 12ft.

To get to the gravels, shafts were sunk by repeatedly lighting wood fires at the bottom of the shafts to thaw the permanently frozen ground. The gravel was then hoisted to the surface for sluicing. During winter there was no running water so the gravels were piled on a surface tip and sluiced in spring when the surface snows thawed. The amount of labour required to mine the gold was considerable, as the ratio of overburden to gold-bearing gravel was high, so claims were gradually amalgamated into larger units which paved the way for mechanisation.

Later mining methods

Whilst larger sluices and more complex water leat systems were devised and used, the first real signs of mechanisation came with

Figure 2. A typical excavation.

Figure 3 A small placer mine separation plant.

water monitors. These were very powerful water jets which were used to literally wash away whole valley sides revealing the auriferous gravels which were then washed through conventional sluices. However, the real problem still remained in that a lot of overburden had to be moved before the gold was revealed and small-scale systems were just no longer economically viable. Large-scale bucket dredgers were the answer and various companies built and operated these dredgers on the creeks from 1905 until the early 1960's. They were truly monstrous machines which being electrically powered required power stations to be built and associated power lines constructed. These generating stations were initially water powered but with the discovery of coal deposits in creeks north of Dawson, coal fired plants were built. Only one of these machines remains relatively intact and has been restored by Parks Canada near the original claim on Bonanza Creek. It had 72 buckets in a continuous line each with a capacity of 16ft^3 and weighing 3340lbs. The dredger had a throughput of 600tons per hour and was equipped with both transverse and longitudinal sluices, which were covered with cocoa mats, covered with expanded metal and Hungarian riffles. The multi-layered transverse and horizontal sluices had surface areas of 1705 and 1100ft^2 respectively. When working on normal auriferous bedrock and gravels the sluices were cleaned twice weekly resulting in typically 50lbs of gold per cleanup. The highest output from some 12 dredgers was in 1913 when 13 tons of refined gold were produced.

Mining today

The big international companies have long gone and the dredges are no more, but many small, usually family owned businesses survive and make a healthy living on the creeks. The big dredges could not get into many of the smaller creeks so these sites tend to be those worked today. The key to their success is in the use of modern earth-moving machinery to get to the auriferous gravels. A typical small mine uses a bulldozer to rip up the frozen muck and remove it. A front loader then scoops up the revealed gravel and places it in a hopper feeding a revolving trommel, which removes the larger stones and cobbles. The gold-bearing sand and small gravel falls through the trommel sides onto conventional riffled sluices where the gold is trapped. Figure 3 shows a typical small placer operation. The separation plant seen in the foreground consists of vibrating screens that reject the large cobbles and gravels. The auriferous sand and small gravel drops through the screens onto conventional riffled sluices underneath. The front loader seen behind the sluice is charging the feed hopper and the loader to the left of the picture is removing the sluice tailings to the tip. Water for the sluices is pumped from the settling ponds so forming a closed system

It sounds easy, but the removal of the frozen overburden is not pleasant. It frequently reveals mammoth and other animal remains and really stinks as it thaws. Some water monitors are still used to mine bench and hill claims but strict environmental legislation now does not allow sluices to run into creeks and rivers. So mines must now drain sluices into lagoons or ponds so that the solids can settle out before releasing the now clean sluice water into the river systems.

One newly opened mine on Brewery Creek uses chemical processes to extract the gold, the first of its kind in the Yukon district. It recorded its first bar of refined gold in 1997, but there was a lot of opposition to its opening and it is under continuous environmental scrutiny and monitoring.

The official records show that in 1993, the year I arrived, the gold output from placer mines in the Yukon was 81863 oz with a then value of C$39.6M. However these mines, which can only operate during the summer months, are costly to operate and their viability is very dependent on the international gold price. This often forces mines to close until the gold price rises again.

My own quest for gold

After acclimatizing myself to the rather laid back lifestyle of the 1974 inhabitants of Dawson in 1993, my quest began. Having acquired maps and more importantly claim maps for the Dawson area from the Mineral Resources Directorate in Whitehorse, my next visit was to the local Mining Recorder's Office to introduce myself and acquaint myself geologically with the locality. Local knowledge is vital and undoubtedly saved me hours of fruitless prospecting and also upsetting some of the existing mine owners who are now good friends. Many of the creeks around Dawson are auriferous and it is reasonably easy to find small gold flecks and dust in the pan but these sites are not commercially viable, even with modern machinery. After a week of hard work on various creeks with little success I decided to move further south into the creeks that flow into the Indian River. There was an immediate improvement in the sightings in the pan and small flakes were more regularly seen. Following my researched chosen creek upstream the size of the flakes increase and the first small nugget found. Eureka! I thought my fortune awaited just a little way

upstream. But as so many prospectors before me have found, the gold suddenly disappeared from the pan. This normally would indicate that the source had been eroded from the adjacent valley sides but investigation revealed nothing more. Other creeks produced similar results with small finds, so the quest goes on.

Conclusion

Once you have been to the Yukon and seen its rugged natural beauty, you have an irresistible urge to return, which drove me to return for further prospecting. The mountain and river scenery is spectacular and the wildlife wonderful but must be respected. After meeting your first bear on the trail you treat them with great respect forever afterwards. If you like solitude and have basic survival skills then prospecting in the Yukon is well worth a try. "What about the gold?" you may ask. Well suffice it to say that in a month with a lot of hard work you could probably get your travel and accommodation/camping costs reimbursed and buy your friends a few beers. If you are not so lucky as to find your fortune then you will at least have had the experience of a lifetime!

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Author

Gordon Bullard BSc Hons (Open), IEng, FIIE is a retired telecommunications engineer. After taking early retirement in 1994 he was able to pursue his lifelong interest in mining and geology by studying for an OU degree in Earth Sciences which he obtained in 1998. His other interests include building large-scale miniature steam locomotives, amateur radio and assisting his wife, Pat, in her garden.

The Seashell on the Mountaintop: A Story of Science, Sainthood, and the Humble Genius Who Discovered a New History of the Earth by Alan Cutler, 2003, William Heinemann, 228pp, £14.99 (hardback) ISBN 0434008575.

Alan Cutler is a palaeontologist and research associate at the Smithsonian Institution at the US National Museum of Natural History. In this, his first book, Cutler chronicles the life of Nicolaus Steno, a brilliant 17th Century Danish scientist who became the most acclaimed anatomist of his time and is now considered to be one of the founders of modern geology. Steno’s story unfolds against the backdrop of a Europe in theological turmoil with Catholics, Protestants and Lutherans vying for religious ascendancy.

Rather than following the apparently incontrovertible learning of current philosophical theories and ‘truths’ contained in ancient texts, Steno argued that scientific knowledge could only be furthered through observation and experiment. An opportunity to consolidate his new ideas came when he dissected a shark’s head and noted that the teeth bore remarkable similarities to glossopetrae, or ‘tongue stones’, and made the intellectual leap to correctly surmise that the latter were a fossilized form of tooth.

This led him to pose fundamental questions about the origins of the Earth, to elucidate evidence for The Flood and to investigate the length of time since The Creation. In addition, he explained why fossil seashells were found thousands of metres above current sea levels and deduced that these fossils must have originally been living animals. Steno received vigorous and sometimes acerbic rebuttals against his theories from many, now much more widely-acclaimed, contemporary scientists and philosophers such as Bacon, Lister, Descartes, Hooke, Boyle and Ray.

Through his extensive travels in the Alps, the Harz Mountains and the Tuscany Apennines, Steno developed his theories on ‘the testimony of things’ which he recorded in De solido, his seminal work on natural philosophy. As well as correctly detailing the sequence of the fossilisation of shells, he established three main tenets, now referred to as "Steno’s Principles", which form a basis for much of our present-day understanding of geology. Firstly, he proposed the "principle of superposition" secondly, he recognised how to interpret the "fining up" of sedimentary strata and lastly, he established the principle of "lateral continuity".

His fascinating story would not be complete without mention that in later life Steno converted from Protestantism to Catholicism, became a priest, somewhat reluctantly was appointed as a bishop and finally, was beatified in 1988. Steno was a devoutly religious but troubled personality and this book cleverly intertwines these aspects of his life with the main story of his passion for natural philosophy or, as it is now termed, science.

Tony Marter Continuing Geosciences student

Sandstone Diagenesis, Recent and Ancient, by Stuart D. Burley and Richard H. Worden (eds), 2003, Blackwell Publishing Ltd., 649pp £60 (paperback) ISBN 1405108975.

"The Oxford English Reference Dictionary, 1996, 2nd ed," defines diagenesis as "the transformation occurring during the conversion of sedimentation to sedimentary rock".

Although the publisher is Blackwell Publishing Limited the book is published on behalf of the International Association of Sedimentologists. The book brings together key papers presented over the last 30 years from a diverse and geographically spread group of authors providing a history of the development in sandstone diagenesis as a subject.

A good introduction by the editors is followed by 38 papers which are presented in themed sections, for example the section titled Eogenesis is split into 3 themes, Marine eogenesis, Non-marine eogenesis 1, warm and wet environment and Non-marine eogenesis 2, arid environment. The introduction by Richard H. Worden and Stuart D. Burley, entitled "Sandstone diagenesis: the evolution of sand to stone" which not only describes the diagenesis process in all its forms but gives clear definitions and explanations of the terms and concepts used in diagenesis. The writing is clear with numerous diagrams, tables and photographs there is even a page of colour photographs. There are also two further pages of colour plates within the papers. A minor criticism, if I may, a book of this type and cost would benefit from having more colour plates I find the inclusion of colour photographs and diagrams a great benefit.

There are two main sections which follow the introduction Eogenesis (Early diagenesis) (17 papers) that which generally occurs at the depositional stage and Mesogenesis(Burial diagenesis) (21 papers) that which occurs post depositional stage ie during and after burial.

Although the book will be in danger of becoming outdated with respect to new research this however will not detract from the value of the book as a reference document. At £60 a copy this is a book for the library shelf and not for the home bookshelf. Sandstone Diagenesis: Recent and Ancient is a good reference document that explains the subject well, the introduction I thought was superb.

Mike Anderson, BA Hons(Open), Msc(Science)

Five Ninety Five and all that: or how OUGS South East Branch helped get me through S267

Mike McGuire

Another October has come and nearly gone. Once again I've committed my exam script to the tender mercies of the examiners and at last I can take a calm look back on the past year's OU course. What was the most memorable event? Was it the Skye granites video where Steve Blake fords raging torrents with his trusty sledge hammer? Well, no – although I am determined to go back to Skye as soon as I can, this time with my geological eyes wide open. Or was it perhaps the soaking morning, during the Penrith weekend, spent among the rhododendrons at Shap Wells beating a health-and-safety-approved resin plate with a sledge hammer in a vain attempt to produce P-waves detectable above the noise from the howling wind and the stream in spate? Well, no again – unforgettable and memorable are not quite the same thing. In fact, there is no contest. The highlight of my S267 year was the three days I spent with members of South East Branch tramping the wilds of Argyll in search of the Tayvallich volcanics, led by Martin Howard - who for once had left his sledge hammer behind.

Old hands at OU Earth Science courses may not be aware that the Tayvallich Volcanics and the date 595±4 Ma are now recorded for future generations of students to remember in Arlëne Hunter's excellent course text which accompanies SXR260 (a.k.a. Durham Summer School which was previously part of S260). Having done SXR260 in its inaugural year, I was fascinated by the whole story of the opening and closing of Iapetus and the various preceding geological events which can be deduced from the rocks of the Scottish Highlands. So, when I saw a trip to Tayvallich advertised for the beginning of June, it went straight onto my Study Calendar. I thought there might be some relevance to S267, and so it proved.

I took my time and travelled to the Grey Gull at Ardrishaig the pretty way – by trains and boats and buses across to Arran and up Kintyre. Even so, I was among the first to arrive on the afternoon of Saturday 1st June 2001. I knew I had come to the right place, for there on the shore in front of the hotel, as promised on the geological map, were the green, shiny Ardrishaig phyllites. The rest of the party straggled in during the evening, having come by planes and cars and trains from the south-east, Scotland and various points between.

Our leader, Martin Howard, is an OU graduate now in the later stages of a PhD at Edinburgh. His work is aimed at developing a tectonic-magmatic model of the Tayvallich volcanics using modern geochemistry. He was the source of much of the geological content of this article and has kindly checked the text for accuracy. Any remaining errors are, of course, my own responsibility.

It seems sensible at this stage to take things a bit out of sequence and say something about the geological background of the area, which Martin explained to us in an entertaining after-dinner talk on Sunday evening. The Tayvallichs occur towards the upper part of the Dalradian supergroup. The context is thought to be the start of the opening of the Iapetus ocean around 600 Ma as part of the (750-550 Ma) break-up of the supercontinent of Rhodinia. The Dalradian consists of, in order:

- the Grampian group (around 750 Ma) and the Appin group, during which low-energy sedimentation was keeping up with the slow opening of a basin
- the Argyll group (tillites around 650 Ma near the base) where water levels were deepening with a small amount of lava
- the Southern Highlands group consisting mainly of turbidites and volcanics

The Tayvallich subgroup forms the last part of the Argyll group. Sediments may have flowed into the basin from both directions in Tayvallich times. The most generally accepted model is of volcanic eruptions into a rift which eventually failed, with the Iapetus Ocean eventually opening further to the south. One of many alternative possibilities, however, is of transitional volcanics at the edge of the rift with the volcanics mainly basalts typical of an opening ocean, but with some more evolved, up to trachyte. The whole Dalradian supergroup is heavily deformed and metamorphosed, much of it in several events. The Tayvallichs occur in the centre of a syncline which plunges to the SW down the spine of the Tayvallich peninsula. Either side of the axis of the syncline the strata dip typically about 80°. The deformation is probably of Caledonian age with metamorphism up to chlorite grade and cleavage generally parallel to the strike of the beds.

Martin explained some of his results to date, but I'll leave him to reveal these when he is ready to publish his thesis.

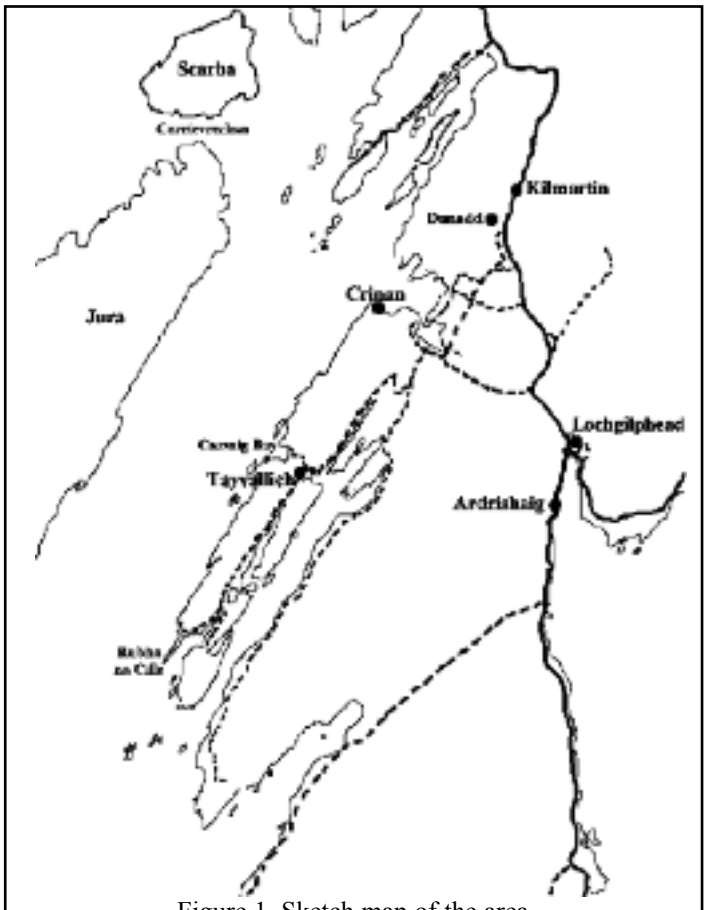

Figure 1. Sketch map of the area.

And so back to a grey Sunday morning, when Jim, Pat and I squeezed into the back of Richard and Linda's hire car and we drove down the narrow road to Rubha na Cille at the south end of the Tayvallich peninsula (Figure 1). The other cars arrived and we set off in good spirits.

The steep dip and the cleavage were immediately apparent in the exposures next to the car park which were metamorphosed hyaloclastites, probably resulting from pyroclastic falls into marine dolomitised limestone. Down the west shore towards the point we found our first lava flows, some massive humps on the foreshore and some increasingly pillow-like structures, though the metamorphism made the pillows very hard to see in places. Along the spine of the point were what looked like prehistoric standing stones but turned out to be exposures of the Loch na Cille boulder bed, a heavily brecciated flow dipping almost vertically. We soon discovered that these hard, steeply dipping breccias are very typical of the area and, together with the very boggy ground between them, make progress painfully slow (Figure 2).

Figure 2. Our leader in typical terrain.

We headed back north past the cars and round the head of one of the small natural harbours which punctuate the coast where transcurrent faults at acute angles to the shoreline offset the more resistant layers. We inspected some paler beds which might have been airfall deposits, some more pillows with various patterns of weathering and some massive lavas humped apparently in a mini anticline. The brecciated flows were becoming increasingly dramatic. In the underside of one we found huge clasts which might have been blasted out of a volcanic vent, some basaltic, some much more evolved and some apparently sedimentary material. Following a narrow cliff path round a mini headland we came across the best pillows yet. Some could be seen in section with feldspar phenocrysts right up to their chilled margins. The lavas were becoming generally more evolved as we went up the coast and eventually we came, by the water's edge, to a large, pale lava exposure full of pink feldspars. This, Martin explained, is where the 595Ma date came from, zircons in the lava having been dated by U→Pb. After this excitement we decided we'd had enough of the difficult terrain by the shore and struggled up the hill to a rough track back to the car park (Figure 3).

Monday we had much better weather with increasing sunshine. We walked up the forest track from Kilmartin towards the coast looking at the various exposures in the cuttings. Again we were crossing the Tayvallich syncline, the rocks getting younger as we

Figure 3. We leave the 595Ma lava.

went up the hill and then older down the other side. The first were deformed sediments of the Argyll group with folds and faults in the more competent beds and heavily cleaved beds in between. Then, part way up the hill, we came to the first basalt, possibly a sill, with spheroidal weathering. The range of rock types increased. We encountered more folded sediments, a basaltic dyke (probably Tertiary), a heavily brecciated fault, a band of dark limestone and a coarse grit with a dark calcareous matrix (it fizzed!) and clasts of quartz, calcite, feldspar and pyrite. These Crinan grits and limestones underlie much of the Tayvallich subgroup.

Figure 4. Sectioned pillow lavas with central voids.

At last, at the top of the hill in a high cutting on the north side of the road, we came to what Martin thought was the most northerly exposure of Tayvallich volcanics. It took a few moments to realise what we were looking at. The road makers had neatly sectioned through a series of pillows to reveal all the details of their internal structures (Figure 4).

Starting down the hill we were back into Crinan grits – quartzites and conglomerates but less calcareous than before (no fizz). Part way down was a pair of very competent beds cutting steeply through an exposure. There was much discussion, and many opinions favoured a dyke. At last, suddenly through the trees, we caught a glimpse of the sea, its startling dark blue against the green causing gasps of delight.

We lunched by an exposure of massive quartzites (with orange and pale bands caused by metamorphic layering of iron) interspersed with schists formed from less competent pelites. We relaxed with a session of find-the-best-quartz-crystal. Some really good ones were found – small but perfectly formed. Finally, at the end of the track, we found what looked like the same pair of very competent beds, but this time the other way up. Opinions in

favour of a dyke were less confident but there was still scepticism when Yvonne insisted on applying her bottle of acid to a sample. It fizzed!! Much dismay amongst the dyke supporters.

Then, since this had been designated a less arduous day, we hot-footed it back over the hill to the pub in Kilmartin for liquid dessert. We spent a relaxed afternoon in the sunshine inspecting the wide range of prehistoric monuments in the area. The Kilmartin valley and the surrounding hills form one of the most important prehistoric landscapes in Britain. Its tombs, cairns, henges, standing stones, hill forts and rock art date from the Neolithic (perhaps 3500 BC) into early historic times. The great rock fortress of Dunadd, which dominates the floor of the lower valley, was probably occupied for over 1000 years and is said to be the site of the inauguration of the Kings of Dal Riada (Argyll) after which the Dalradian is – rather inaccurately - named.

Tuesday dawned clear again but after overnight rain there was a promise (later fully realised) of more rain to come. We drove to Carsaig Bay and set off through soaking grass south-westward down the peninsula. There were good views of Jura and, to the north, Scarba with the treacherous gulf of Corrievreckan between. Martin showed us where, in the nose of the plunging syncline, the northern end of the main outcrop of the Tayvallich volcanics occurs. For half an hour or so we played a happy game of "hunt the contact" and found at least three clear places where the base of the massive basalt flow overlies calcareous quartzites. We saw possible evidence of pillows immediately above the contact and clear columnar jointing higher up in the flow. We went down to the shore and onto a tidal islet which is shown on current maps as basaltic but which contains strange orange-coloured lumps up to 2m across which Martin assured us are dolomite.

Over lunch, the hills of Jura gradually disappeared from view and, by the time we set off again, a typical Scottish steady rain had set in. Up to this point, as what a friend of mine calls a "sprog geologist", I had been making at least a few notes of the main things we had seen. My naivety was, of course, soon spotted which is how I come to be the one writing this article. However,on Tuesday afternoon I was noteless as the skill I most comprehensively failed to learn at Durham Summer School was how to write inside a polythene bag. I have a few photographs, but otherwise must rely on memory. I recall a cleft running down to the shore with a Tertiary dyke (a real one this time) in it. The sides of the cleft showed sections through coarse grits with turbidite-type fining-up sequences and lumps of limestone. Also perhaps the most massive brecciated flow of all which we spent quite a long time examining (i.e. sheltering under) and which contained huge clasts of practically everything you can imagine including lumps of dolomite (Figure 5).

Most of all I remember the "yomp" over the hill, the embarrassed sneak through the farmyard under the amused gaze of the farmer and the three miles (1 Scottish mile is equivalent to about 1.5AU (Astronomical Units)) back along the road to Tayvallich and the cars at Carsaig.

Finally, I should say a few words about my companions on this escapade. I have often found it hard to mix with groups of strangers. Particularly when nearly all the rest know each other, one can easily be made to feel an outsider. This occasion could not have been more different; I was made to feel really welcome. The sense of shared interest and enthusiasm, even the shared hardships, not only made for a very enjoyable trip but also gave a major boost to my flagging morale. In what has been, for personal reasons, the most difficult OU year for me so far, I have several times almost abandonned S267 in mid stream. But on this trip I learnt several things which were relevant to the course, I saw many things which helped to put the course material in context and my enthusiasm received a major boost. So to Martin our indefatigable leader, to Geoff my tolerant room-mate, to Richard my kind chauffeur, to Yvonne who organised everything superbly and to all the rest of you, thank you very much. I look forward to meeting you again soon.

Figure 5. Bigflow.

To which last sentiment there is one sad exception. Yvonne contacted us all not long after the trip to say that Jim Teal had been taken ill and died on the journey home. Pat and I shared the back seat of the car with Jim for many a bumpy Scottish mile, and I talked to him through several more miles of walking, both arduous and enjoyable. I found him enthusiastic, wryly amused, tough and uncomplaining. I am sure many people will miss him a great deal. I am glad I met him and sorry I shall not do so again.

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SXR260 – The Geological History of the British Isles

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Author

Mike McGuire started studying with the Open University after taking semi-retirement from a job in railway research and IT systems and has successfully completed S103, S260/SXR260, S267 and is currently studying S268. His aim is to achieve an Earth Sciences named degree and see where it might lead.

Cooking and Geology in Iceland 2003

Eileen Fraser

Figure 1. Route taken during the trip round Iceland.

Geology one can understand – but cooking! Two years ago whilst on a trekking holiday to Iceland and, in one illadvised moment, I announced that if they ever needed a cook for the trip to let me know. Unfortunately the Director of the company was also the leader and took note!

Two years later and I have just returned from Iceland having had two wonderful weeks of geology and, of course, group cooking (usual job accountancy!- how different is that?); (see Figure 1 for route).This account is not intended to be a technical treatise on the geology of Iceland as that is better left to the experts, but a flavour of features and variety of geology that can be found there. The group were interested in anything natural and I tried my best to remember some of the crystallography from S260 and geochemistry from S267 and S339. I could bore the socks off anyone who wanted to listen to me and explaining crystal crystallization while standing on an open hillside took some beating – but they did ask!!

The trip started in the Eastern fjords, which are very like Scottish sea lochs with much higher mountains. The hillsides are very green , with wonderful wildflowers and birds, and valleys full of waterfalls and basalt sills, dykes and glacial erratics, striated rock pavements and residual snow and ice in the gulleys and small glaciers. The mountains are tabular and show clear evidence of repeated horizontal flows of lavas rising up to over 1000m. The walking is spectacular, some over waymarked footpaths but much over small sheeptracks and footpaths known only by local people. The bedrock is basalt: everywhere!

The northernmost fjord, Borgarfjördur, where we started, has spectacular pale-coloured rhyolite mountains which shine red in the reflected evening sunshine (Figure 2). This valley also has a dark basalt mountain range with a large breche (U shaped door) in the middle, large enough to fly a plane through. It appears to have been formed by a glacier cutting through a gap in the mountains, further modified by sharp arêtes on either side of the range where glaciers must have formed. There is a puffin colony in the sea cliffs and a very good 'rock shop' which has the largest piece of jasper I have ever seen. Our visit also coincided with the Icelandic August bank holiday so there were B-B-Qs and wild parties going on all through the 24 hours of daylight.

The access to the next fjord to the south, Lodmundarfjördur, is by foot over a steep mountain pass, with a river crossing! Otherwise there is a jeep track round the head of the fjord (about 30kms) or by small boat from Seydisfjördur. The only accommodation is provided by an Icelandic family who come into the valley every summer and open up their farmhouse for sleeping-bag accommodation in the loft (Figure 3). The valley is otherwise deserted, apart from an eider duck farm, a small white church and the ruins of a house with a wild rhubarb patch! The mountains are again over 1000m and tabular basalt. I did find a beautiful nodule of olivine and peridotite. The paths are littered with specimens of a dark green mineral and basalt with amygoloidal infilling. The geological exploration possibilities are endless in this isolated valley and local people tell of crystals which can be found (Iceland Spar springs to mind!) and the two days spend here were definitely not long enough! The family in the farmhouse were very welcoming, and at one stage there were over 35 people all vying for space: very cosy.

Continuing south, the next fjord, Seydisfjördur is again accessed by foot over a high mountain pass. However as I was the cook and general dogsbody, I had the pleasure of going round by small boat with the food and gear. This gave me fine views of the huge columnar basalt cliffs and a puffin colony, seaweed-eating sheep and nests of fulmars. Seydisfjördur is the ferry port for the Faeroe Islands and Denmark and the small picturesque town is built round the head of the fjord, with a fish factory and a car ferry dock. Behind it the valley rises up, carrying the road over to Egilsstadir, the nearest town with an airport.

After two days in the eastern port of Seydisfjördur we picked up our bus, a 4-wheel drive 30-seater, which accommodated the eleven of us plus all our gear and boxes of food and equipment. The driver was Icelandic which gave us the opportunity to ask all sorts of questions about the area. Our route took us out of the beautiful eastern fjords into the interior of Iceland. Our destination was the mountain hostel to the north of the Vatnajokull ice sheet, just below the Kverkföll thermal area and the source of the

Figure 2. Borgarejördur: rhyolite mountains.

Figure 3. Lodmundarfjördur.

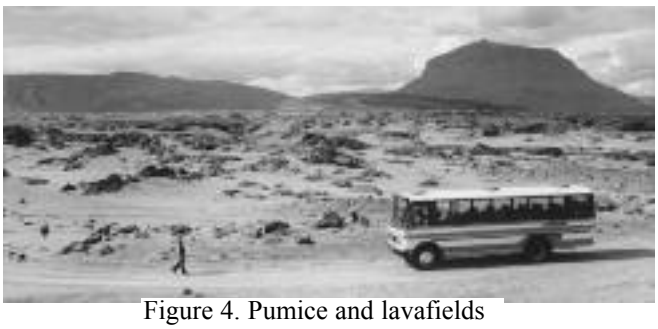

Figure 4. Pumice and lavafields

Kreppa river which eventually joined the Jokulsa à Fjollum river flowing out to the north coast.

Our journey took us initially across farmlands, which eventually gave way to bare lava fields, littered with isolated spatter and cinder cones, tuff rings and shield volcanoes. Nothing can prepare you for the sheer scale of the events which must have formed this amazing landscape (Figure 4). There were fine views of Askja in the distance and swathes of very pale deposits lying on top of the basic lavas. On examination, these pale deposits were found to be a very fine pumice almost cellular in construction and certainly too delicate to bring back. These had emanated from Askja in the spectacular eruption which formed the caldera at the end of the last ice age. One particular solitary mountain Herdurbreid (Queen of Mountains, 1682m) stood out from all the others and was a classic example of a tuya (Figure 5). This had erupted beneath the glacial ice which must have been over 1500m thick at one time. The steep sides had been formed as the lava rapidly cooled and there are examples of pillow lavas on the flanks, and columnar basalts. However this volcano must have protruded just above the ice sheet as there is a raised peak in the middle which with the residual winter snows makes it look rather like an iced cake, with a cherry on the top!

The journey continued south through the lava fields, with the dirt and stony track becoming more and more convoluted until we could see our destination: the ice cap with the distinctive Kverkfoll (Crack in the Mountain) and the odd wisp of steam rising from the fumaroles on top. As one travels closer the edges of the ice sheet seem huge and very dirty and with numerous crevasses and moraine everywhere from previous advances. In contrast the ice sheet is white and looks very close. This is quite deceptive as it is in fact a three-hour walk from the hostel through the morraine to the foot of the ice and a further three-hour walk through the snow fields to reach the first thermal areas. A walk to see these is a full day's expedition with a trained mountain guide, but is worth every bit of effort, as the deep crevasses and cracks in the ice billow with steam from the volcanic activity below and it is easy to appreciate the massive forces that are at work. It is thought that the Iceland hot spot also lies below this part of the ice sheet which makes it even more awe-inspiring. If it is windy there is steam and a smell of sulphur everywhere and bright yellow sulphur deposits and bubbling rockpools with blue-green talcum-soft mud. In winter when the snow is deep these clefts look like brown meringue! It is an unique and very special place.

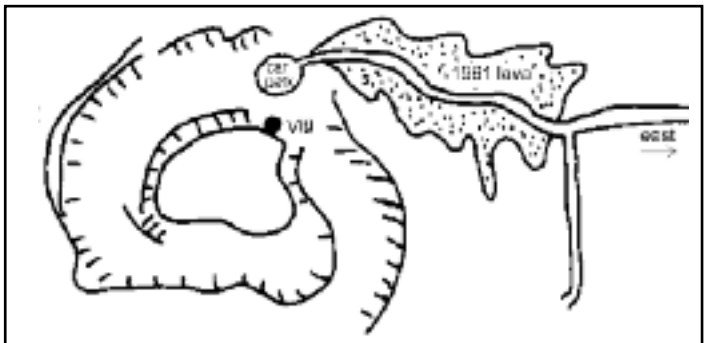

Figure 6.Sketch map of Askja crater.

After two days we left the ice sheet and drove north to Askja, parked on the crater's edge and walked across the flat floor for about three kms (see Figure 6). The main crater at Askja is about 20kms in diameter and was formed by a huge explosion which occurred at the end of the last ice age and covered north-east Iceland with lava and ash for hundreds of miles. A later explosion in 1875 formed a further collapsed crater which is now filled by a cold water lake which is 220m deep and fills the eastern side of the original crater. Since then lava eruptions have occurred, the last being in 1961. These appear to have been more viscous in nature as there are massive fields of aa lava with some slab and pahoehoe lava in evidence. It is a rich reddish-black colour and looks very basic in nature. The scale of the whole event is daunting and there is a feeling that this area has not yet finished erupting.

However, our destination was a small hot water crater known as Viti (Hell's Mouth) at the edge of this lake (Figure 7). After a scramble down of about 50m it was possible to reach the edge of an opaque blue lake and swim in the warm waters which are obviously fed by a volcanic vent from below.

After a thorough wetting from rain as we returned across the crater, we continued northwards for about 5 hours to the coast, crossing the pelagonite belt of Northern Iceland and progressive-

Figure 5. Herdurbreid; Queen of Mountains, 1682m.

Figure 7. Viti crater, Asjka.

Figure 8. Jokulsa a Fjolm Valley.

ly older lava fields and passing many cinder cones and mountain groups. The whole of this area is drained by the Jökulsá a Fjöllum river, which in the past has been the focus of jokulhlaup flood events such as was witnessed on the south coast of Iceland after the last eruption under the ice cap. This river from the source under the ice sheet had now turned into a massive waterway 0.5km wide and 100m deep (Figure 8). At Dettifoss the waterfall is 44m high and has a mean flow of 220m^3 per second rising to 1500m^3 at maximum snow melt. The spray can be seen from miles away and the noise is deafening. A wonderful walk can be taken all the way along the west side of the river for about 25kms out to the coast. It is a long walk and should be done in at least two days to appreciate the incredible basalt features. The layering of the Pleistocene lavas, tillites and later overlying lavas can be clearly seen (see Figure 9). At Vesturdalur there are large volcanic plugs where the lava has erupted through tephra which has meant that it has cooled in all sorts of amazing shapes (see Figure 10). Along the route there are massive organ-pipe-sized columns of basalt and sills and dykes and where small streams flow into the river there are oases of greenery with angelica and grasses and flat meadows where orchids and other wild flowers grow.

After taking time out for whale watching at Husavik, the last place we visited was Myvatn (Midge Lake) which has Krafla behind it. Its recent lava eruptions from 1975 to 1984 are still evident by black swathes across the countryside with steaming hillsides, areas of bubbling mudpools and whistling fissures where steam and gases are being released under pressure. The whole area is interesting with Mount Hverfjall, a large cinder cone over 1km in diameter which can be circumnavigated and Dimmoborgir, an area where a lake has drained away leaving some interesting lava formations and a region of rootless craters where lava has hit the water and exploded to give very realistic cratering without the volcanic vents. The lake itself abounds with

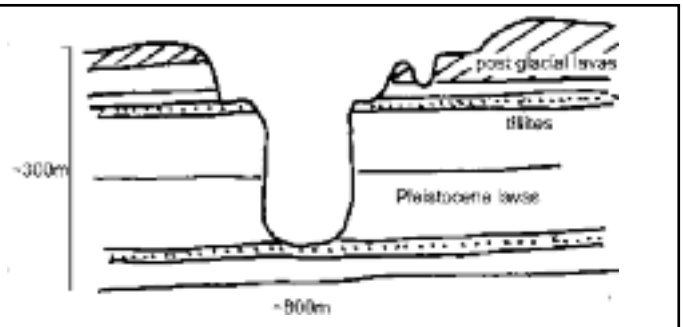

Figure 9. ~Strata visible at Jokulsa à Fjollum.

Figure 10. Vesturdalur.

birdlife and the freshwater diatoms which are found in this shallow lake (only 2m deep) have given rise to a diatomite industry. The electricity is generated by a geothermal power plant, which has not been as successful as planned, as the pipes are constantly being corroded and the earth movements along the fissures and mid-ocean ridge in this region cause a lot of breakages. However, it is a very impressive set–up and dominates the thermal area around the Krafla caldera. It is a good place to end a trip and again the area has a very raw feeling about it, as if it is only biding its time!

Iceland is a country which, if you are interested in geology, wildlife or botany, has so much to offer. The geological history is very complicated and the features are too numerous to go into detail, but everyone who visits returns with some of the magic.

And – oh – the cooking – well, the fish is straight from the sea, cod and arctic char, Iceland grows small salt potatoes and of course there is also lamb, with geothermal heated greenhouses providing the vegetables, so the food is delicious.

It is now back to the day job and the next TMA! I hope I will be able to go back to Iceland again sometime as it is a very special place. How about an OUGS fieldtrip?

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Author

Eileen Fraser, Diploma in Earth Sciences (Open) and continuing Earth Science student is an accountant who runs her own business in Cheshire. She is married with two grown-up daughters one of whom is a geophysicist working in a goldmine in Western Australia; the other is a media expert. She has always been interested in the countryside and geology and some years ago decided to find out more - hence the studying. She is a Committee member of the local GA, an occasional Earth Science lecturer for U3A and an enthusiastic amateur geologist.

The "Giant Astronaut Theory": or why the dinosaurs did not become Extinct, merely emigrated

Genni, Daniella, Natalie, Melanie & Terri Pierce-Butler

Dinosaurs evolved rapidly throughout the Cretaceous, over about 80Ma. Some species, particularly the raptors, had a large cranial capacity and it would be presumptuous not to consider the possibility of intelligence developing.

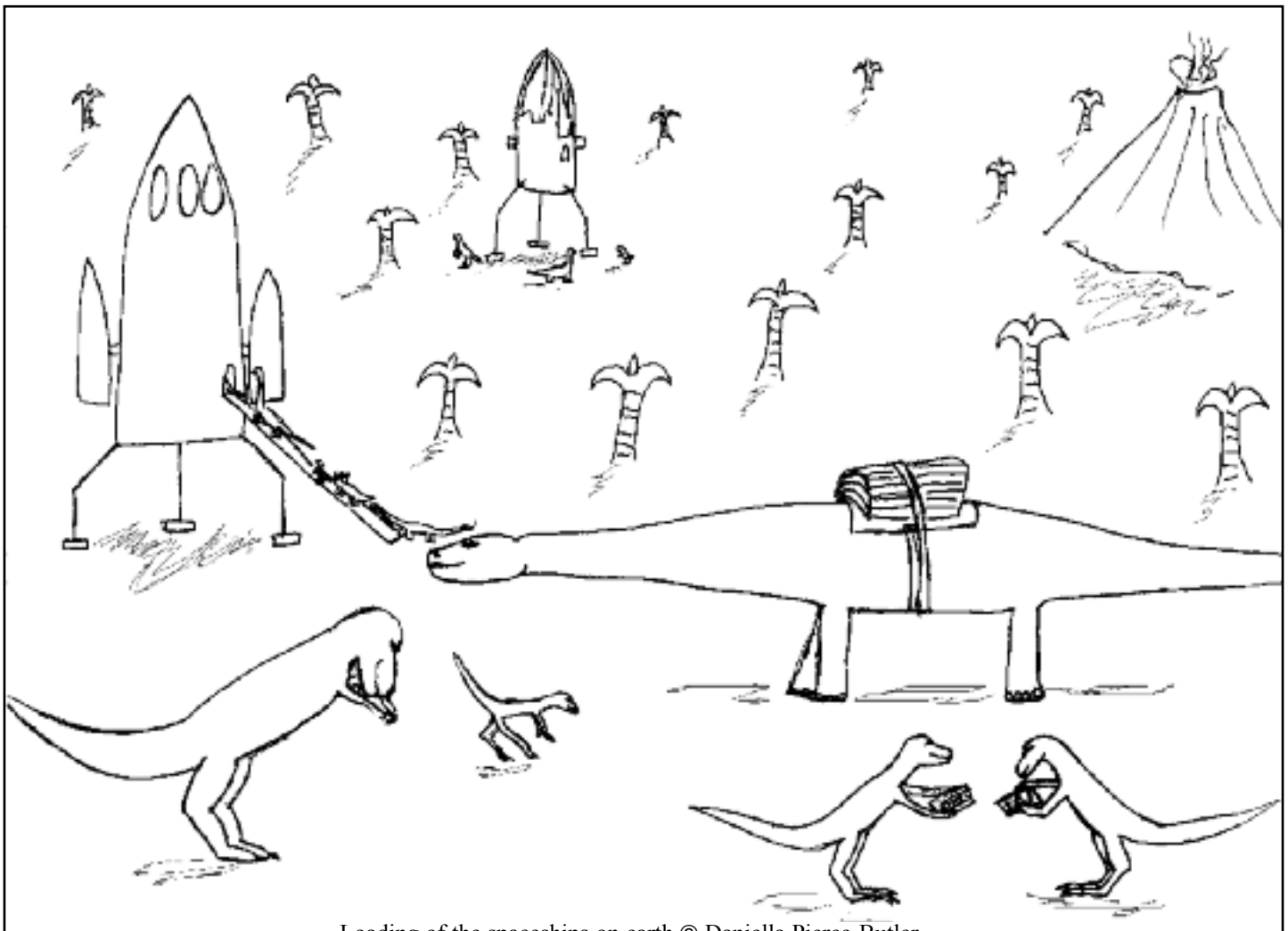
During the late Cretaceous environmental conditions were deteriorating; there is a great deal of evidence for this in the geological record. The question is ‘what would an intelligent species do about this?’ One obvious answer is to emigrate to other planets. That they did this is evidenced by the gradual decline of dinosaur remains in the fossil record, which has been put down by previous authorities to graduated extinctions. We propose that this apparent decline was caused by the development of a space programme and the subsequent emigration. (After all humanity has moved from caves to space travel in less than one million years.)

There is generally less iridium in the earth’s crust than would be expected in comparison to chondritic meteorites, from which the earth accreted in the first place. We propose that this is accounted for by mining processes during the Cretaceous. Iridium is a hard, dense metal with a very high melting point, useful electrical properties and the ability to absorb hydrogen and oxygen in its tertiary valence state. This would have made it invaluable for a developing space programme.

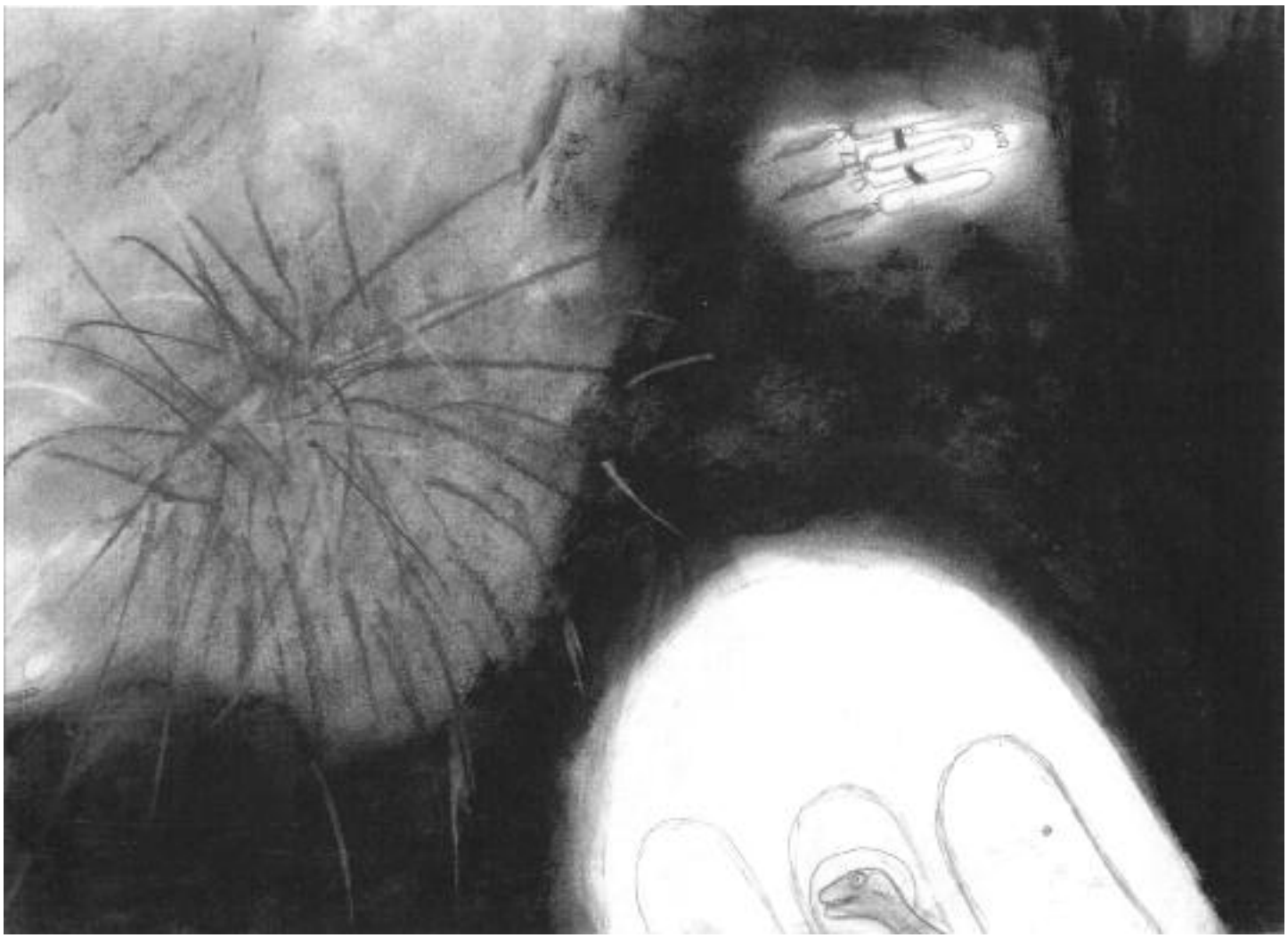
It would seem reasonable for nose cones of re-entry vehicles to be made from iridium. Ablation during re-entry and the occasional crashes would account for the smeared-out nature of the "iridium spike". These crashes (bearing in mind the size of the space craft needed for dinosaur ‘astronauts’) would give similar results to multiple impacts by meteorites.

We propose that drilling into the centre of the Chicxulub crater would provide evidence in the form of remains of a spacecraft, although unfortunately any giant astronaut remains are likely to have been vaporised. We feel that this hypothesis should supersede current ones, as it does not require exotic mechanisms such as impacts by ‘high iridium’ asteroids. After all, a space-faring civilisation would be expected to be able to defend itself against such occurrences.

We think that this explains the slow decline in dinosaur numbers well before the KT boundary, such that there is not the thick layer of dinosaur bones expected after a mass extinction. It may also



Loading of the spaceships on earth.© Daniella Pierce-Butler



A crash from space © Genni Pierce-Butler

explain the small 'arms' of certain predatory dinosaurs having been evolved (or genetically modified?) for tool use.

Delays in publication of this theory are due largely to the fact that the main author (Genni) was only five when it was first proposed ten years ago.

Authors

A short family introduction: Terri is doing a BSc with the OU at present, based on Earth Sciences; Melanie used to be a research scientist for the MoD - Xray crystallography and is now looking after the family; Natalie, now 21, has just finished a BSc in Psychology; Genni, now 16, is doing GCSEs this year; Daniella, now 12, has always been fascinated by dinosaurs. Genni first inspired the idea when she was 5 and wrote in her schoolbook about how the extinction of the dinosaurs had been caused by a giant astronaut crashing to the earth (we had told her about the Alvarez theory). Since then we have revisited the idea on several occasions and discussed it as a family, refining the various concepts. In the course of writing assignments for S369 Terri put this theory forward as an alternative to more conventional ones, having learned more corroborating details from his course. His tutor, Steve Killops proved openminded enough to suggest wider dissemination of this approach. Melanie and Terri worked together on formulating the theory as it is written here.

A weekend in the Vosges

Gill Ewing

My birthday is in August and last August I was lucky enough to be given a fine geological hammer and a definitely up-market handlens – which came with an invitation from my husband to spend a weekend in the Vosges, inaugurating these splendid gifts and exploring some of our regional geological delights (Figure 1).

I therefore busied myself on the Internet trying to work out a suitable route which may yield us the most interesting geological finds and, although not all the locations were fruitful, we had a wonderful weekend and came home with the car definitely heavier towards the back and the hammer and handlens well and truly broken in!

First, here is a rough summary of the geological history of the Vosges:

In Precambrian times (4600 – 570Ma) the gneisses found today in certain areas of the Vosges were formed from relics of ancient mountain ranges. The oldest, in the Climont region of Val de Villé, have been dated at around 1 billion years old and the most recent can be seen near St Marie Aux Mines. These formed the backbone of the Caledonian Range 430Ma ago.

Towards the end of the Paleozoic the Hercynian range occupied a large part of Europe, stretching from Britain to Bohemia. It was raised mainly during the Carboniferous between 340 - 280Ma ago as a result of continental collision between two slabs, one producing the Northern Vosges (sandstone) and the other the middle and Southern Vosges (granite). The suture between these two slabs is visible today at the bottom of the Val de Villé, between Lalaye and Lubine. During that time various geological phenomena took place with volcanic eruptions, deformation and folding, metamorphism of ancient rocks and production of granite.

During the Permian, about 250Ma ago, a major climate change took place and the area became much more arid. The lakes dried up and the forest regressed to be replaced by vast wind-swept tracts of land between the peaks. The Hercynian range was eroded and the finest sediment was swept by the wind to form sand dunes, the orientation of which shows that the dominant winds at that time were easterly. These Permian aeolian dunes gave rise to Champenay Clay which is still used for construction. Volcanic activity during this same period produced the red porphyry found at Nideck in the Bruche valley today.

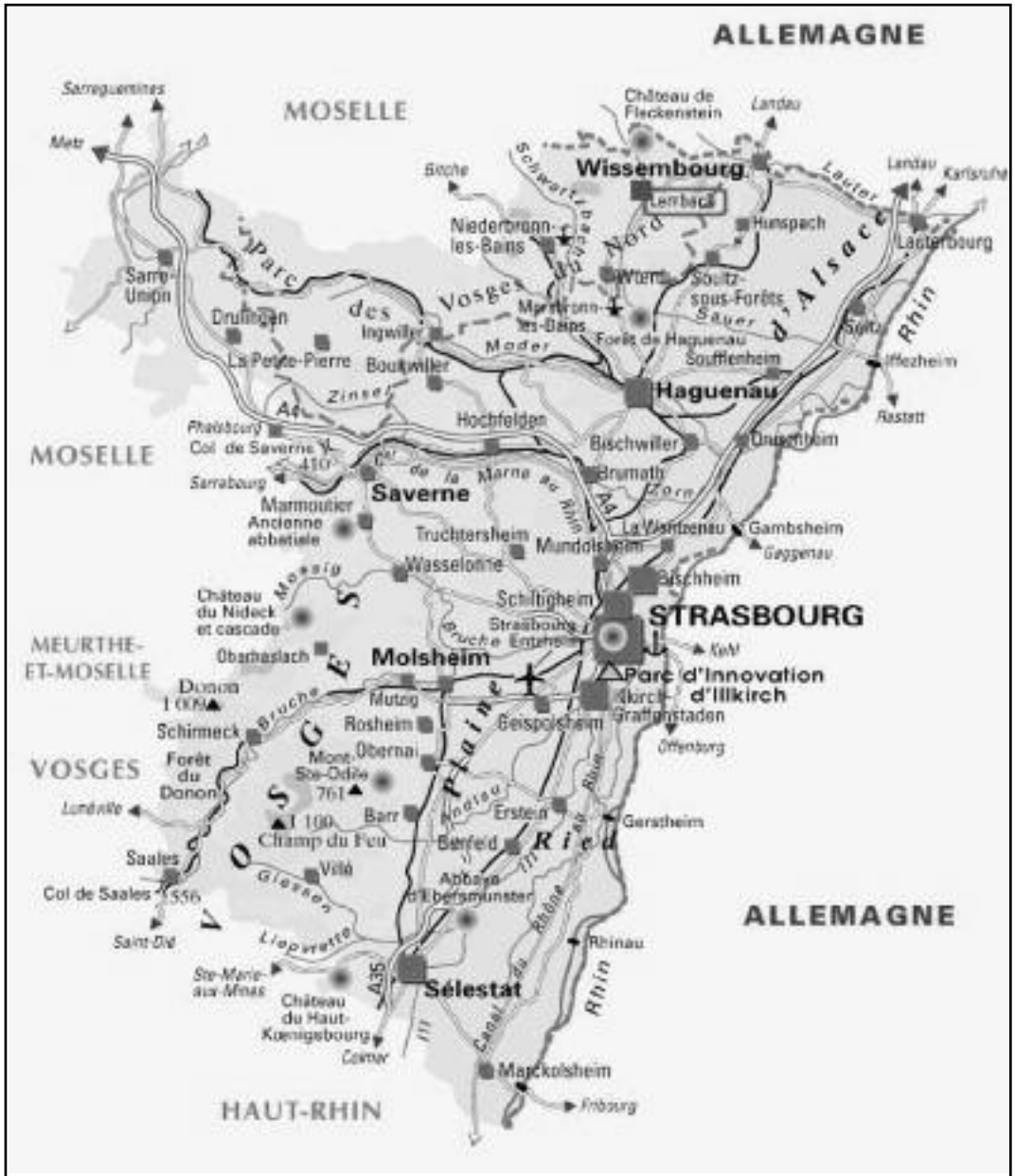


Figure 1. Map showing the location of the Vosges.

During the Triassic, the Hercynian range continued to erode and the entire eastern part of France became a transit zone for erosion products from the Paris Basin, swept across the country by a network of rivers into the Germanic Sea which then covered a large part of Eastern Europe. Prolonged droughts were punctuated by shorter wet periods during which large quantities of sand and pebbles were carried along and then deposited as the water courses dried up again, leaving an alluvial plain which eventually built up into the vast banks of sandstone found today.

220Ma ago the Vosges and Alsace formed a low plain bordering the sea with a vast delta channelling water, eventually

Figure 2. Vosges Valley.

giving rise to the clay used later to build Strasbourg cathedral. By the Upper Triassic the Germanic Sea had regressed into a series of lagoons into which were decanted clay particles enriched with calcium, which gave rise to iridescent marls in greens, reds and violets. The hot Triassic climate dried up these lagoons and potash deposits developed in the Mulhouse region: the last remaining signs of the lost Germanic Sea.

During the Jurassic period the sea invaded the Vosges and Alsace once more and this was when the bituminous schists formed. Shallow warm seas covered Europe for nearly 20Ma and about 125Ma ago the area occupied by the Vosges was transformed into a huge carbonate platform with the formation of oolitic sands. Reefs in Southern Alsace towards the end of the Jurassic are most visible today in the limestone cliffs of the Alsatian Jura.

About 150Ma ago the Vosges and Alsace emerged from the water once more. For more than 100Ma, until the middle of the Tertiary, it existed as emergent land under a tropical climate. This was the time of flowering plants and dinosaurs but the main event of which we have evidence here was the formation of the Alps.

Around 50Ma ago during the Eocene a north-south oriented depression formed in the middle of the emergent Vosges and the Black Forest, which gradually broadened to a width of about 30km, extending from Basle to Frankfurt separating the two ranges; the plain of Alsace had arrived. Along the fractures between the plain and the Vosges lava was erupted in association with the formation of the Alps further south. In the meantime the Vosges were raised further and erosion increased. In the region of the Ballons in the southern Vosges the cover was eroded and old Hercynian basement revealed. In the north, where the Vosges were lower, erosion stopped at the Triassic sandstone.

During the Quaternary, 2Ma ago, the climate deteriorated and ice covered Northern Europe as far as the Alps. The Lorraine slopes of the Vosges developed a sea of ice over about 40km. The Alsatian side is much steeper so that smaller glaciers carved their way through the valleys and their effects are seen today in the High Vosges. Successive periods of cold and warmth left their marks and the latest period of climatic warming, begun 10 000 years ago, saw the last glaciers disappear from the Vosges, leaving evidence of their existence only in the relief we see today. (Figure 2)

We live at the northern end of the Vosges in the Northern Vosges Regional Nature Park and right next door to an interesting geological feature known as the oil lagoons of Pechelbronn. 40Ma ago the sea, which then occupied the current location of the Alps, invaded the Rhine depression and a climatic change, which led to 10Ma of hot dry summers, turned the plain of Alsace into a dead sea bordered with swamps. This was when potassium and gypsum were deposited in the Mulhouse region of South Alsace, where potash is still exploited today. Lagoons of briny water developed with plankton proliferating on the surface. As these died and fell to the bottom of the lagoons stagnant water preserved their remains under anoxic conditions. Chemical maturation enriched this organic material with hydrocarbons and oil formed as a result. This oil was exploited from the 18th century to 1963: it was one of the world's first oilfields. Local springs in the area now provide hot water which is currently being exploited industrially by a geothermic company.

However, to get on with our trip. Our first port of call was Bouxwiller, west of Haguenau where I hoped to find the remnants of a vast lake which formed there during the first half of the Tertiary. A 50Ma old community of fossils in clay and calciferous rock was what we were looking for, but alas it is long gone and the only quarry we found was the usual Vosges sandstone, of which more anon.

We turned south and headed for Dabo rock, near Saverne. John is a keen cyclist so he knows our area like the back of his hand. He had recently climbed a col which led him to Dabo rock, a well-known local landmark peak, and he thought there were interesting markings in it (Figure 3).

Each of these deposits shown in the photo may have been made in minutes, hours or days, or there may have been centuries between each one. Oblique layers, several millimetres thick were built up, according to current fluctuations, with coarse sandstone full of pebbles demarcating each layer as can be seen in the photo. Dabo rock is now the culmination of a considerable climb, yet the signs of ancient currents are still clearly visible today.

Our next port of call was Nideck in the north of the Bruche Valley, an area of aeolian dunes, although these are difficult to see today because the whole area is well forested!

However, during the Permian, volcanic eruptions took place at the same time as the dunes were developing. The Château de Nideck (ruins) was built on red porphyry derived from the ancient lava. A fine waterfall shows columnar bedding of this rock with a total thickness of 200 - 300m (Figure 4).

This porphyry is very hard rock (as my hammer could tell you!), a reddish violet in colour and sprinkled with particles of white quartz and feldspar with angular fragments of darker volcanic rock. In fact, the red porphyry developed from the cooling of very viscous lava produced by the above-mentioned volcanoes and classified as a rhyolite. The Nideck volcanoes became extinct 250Ma ago and the location of their craters is unknown. This formation of red porphyry is the only remaining evidence of those volcanoes. We were able to find excellent samples without attacking any of the formations themselves. The castle ruins are a tourist spot and well signposted; you need good walking shoes as it is a relatively fun walk down to the falls, not to mention the climb back up!

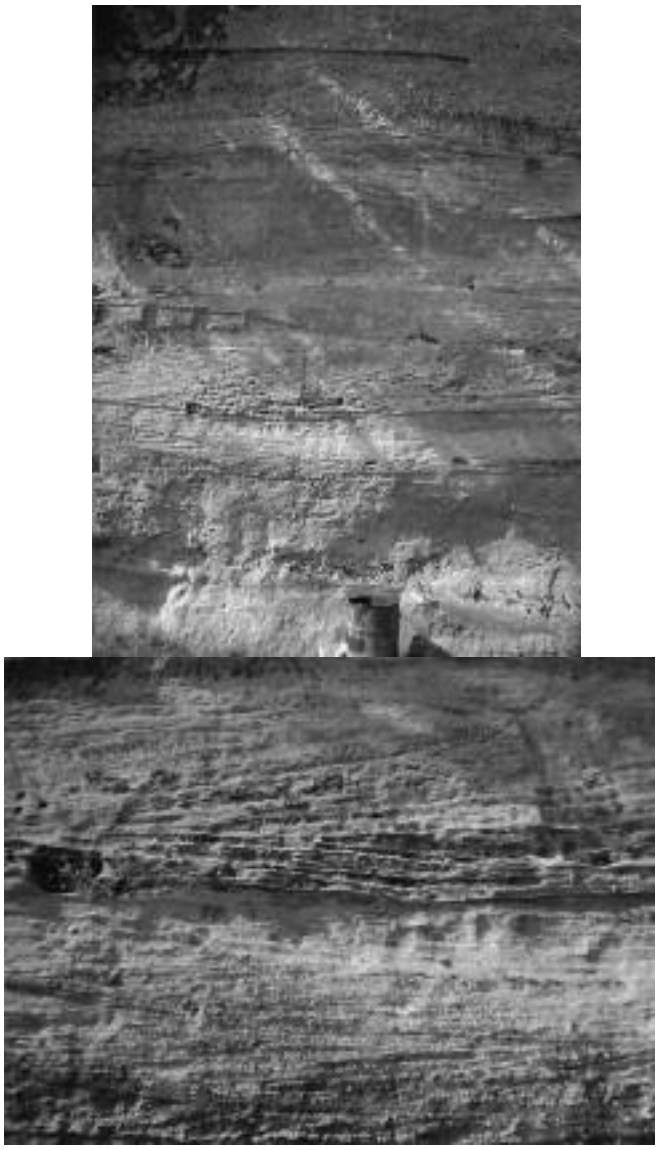


Figure 3. Dabo rock with detail (drum for scale).

Continuing south through the Bruche valley, which hosts all the high spots of Vosges geology, we visited the villages of Russ and Hersbach which face each other across the valley. Hersbach has a huge quarry which is exploited today by Wenger et Petit. My notes told me that these quarries exploited ancient reefs from the Devonian (375Ma ago) when Alsace was in the tropics. Grey limestone with a reddish tinge, known as Russ Marble, is quarried here. To the western end of the quarry is a different area revealing thin slabs of grey or black schists with concentrations of pyrite. Black schists are said to hold fossil sponges, holothurians, gastropods and lamellibranchs as well as molluscs and radiolarians deposited along the littoral of a shallow sea.

This was a disappointment to us: we found the schist certainly and had a closer look, picking up a few samples that were lying around, but not a fossil in sight that we could find. Most of the area was well fenced off by the quarry company and on a Saturday afternoon no-one could be found who might let us in for a closer investigation, so we headed for Climont in Val de Villé, north-east of Séléstat, to hunt for Precambrian rock instead!

This was difficult as sandstone covers everything in this area and we toured the region of Climont which is known to have outcrops of gneiss and schist which have been dated at 1 billion years, hoping for a sight of such an outcrop. All we could see was sandstone and yet more sandstone and finally we decided we had done enough riding and it was time to walk again. We spotted a nice trail leading up a pretty steep little hill that seemed just right for stretching our legs so off we went, hammer in rucksack and handlens at the ready anyway, because even sandstone may have some interesting inclusions now and then. The trail zig-zagged up the hill, through the forest, the soil remained infuriatingly red, until we came to the end of a zig about halfway up and began to zag back across the hillside when rock suddenly emerged through the red soil as definitely grey and schistic: we had stumbled (literally) onto an outcrop of Precambrian gneissic schist!! We took a few samples and that was the only small area where this rock was visible because the next zig was back in the sandstone again and indeed we found ourselves in a war zone. The top of the hill still bore all the signs of devastation caused by the December 26th 1999 hurricane which we remembered only too well. By August 2001 the broken and fallen trees were pretty much dead up there and not yet cleared away; we had to give up our attempt to reach the summit because the fallen trees were just too numerous to clamber over. We got some photos though!

Figure 4. Organ Pipe, Nideck.

After a pleasant stay in St Dié (the Ibis hotel usually serves us well) we set off south again in the morning to explore the Southern Vosges (granite). We drove through Ste Marie aux Mines, a town squatting in the bottom of a high-sided valley that must be very dark in winter! Here there is 600Ma old gneiss with lens formations of marble formed from the recrystallization of calcium compounds (thought to be from ancient coral reefs) during metamorphism. Apparently ancient eroded mountain ranges were deposited as sand and mud in geosynclinal basins, subducted and subjected to 9000 – 10 000 times atmospheric pressure at 750°C to form this gneiss. Vertical movement brought it to the surface and erosion produced the current outcrops. These were impossible to visit: we spotted one or two outcrops towering over our heads at the top of the very steep valley, but nothing would have been reachable without a major expedition. We did finally obtain a sample on the way back home from a slightly different area nearby.

340 – 280Ma ago the Hercynian range was lifted and folded and magma rose and crystallized to produce the various Vosges granites. I confess to a particular love of granite and I was not to be disappointed that Sunday in August as we headed along the peaks route towards the Ballons des Vosges. We stopped at various pull-ins and spots with panoramic views where granite boulders were used with gay abandon to mark parking perimeters or even provide picnic tables and benches. There are some enormous quartz and feldspar crystals in some of the granite found along this route and all are fascinating. The granite is quite pink with feldspar in some cases, pale grey with quartz in others and all like rich fruit cake! I collected so much granite of various shapes and hues, the car was beginning to groan by the end of the day.

We took in the Petit Ballon and Grand Ballon, eroded remnants of volcanic granite hills but these are heavily tourist-infested so we decided to head for home. In a way we are lucky to live at one end of the Vosges because the whole area is geologically fascinating and you can drive the whole length in about three hours. We spent a very happy two days there and intend to repeat the experience. Our September holidays took in the Cévennes and the Pyrenées Orientales – but that is another story!

PS If you read French there is much information to be found on a website called La Passion des Minéraux et Fossiles: La Région Alsace. The link is: `http://jasper.kioskdu.com/r_g2.html`

Author

Gill Ewing is a professional scientific and technical translator working from French into English and working towards a BSc in Geosciences with the OU. She has lived in France with her family for more than 30 years and holds a MA from Edinburgh University (1971).

Book reviews

Two Geowalk Guides of potential interest to OU students Newlands Corner – Albury Geology Trail. Produced and published by Surrey RIGS 2002. 23pp. £1.50 (paperback)

The first is a geology trail from Newlands corner to Albury described by Surrey RIGS. This slim booklet is beautifully designed and slips easily into the pocket. It is a substitute for notice boards along the trail. The walk itself starts in the car park at Newlands Corner near Guildford, where the only board, detailing the route, can be found. The walk is supported by echinoid way-markers and, with the booklet, is easy to follow. The board is reproduced as the centrepiece of the booklet. It shows the route in an excellent block diagram that cleverly illustrates the geological structure on this northern limb of the Weald. Directions are clearly marked from each stop and all the stops are explained by a double-page spread that shows the position on the block diagram as well as in the stratigraphic column. The supporting text is concise and very informative with relevant pictures and diagrams to highlight the main points of interest. Each page also has drawings of typical fossils of the age and boxed insets about the local history and nature where relevant.

I strongly commend Margaret Hargrave for her excellent diagrams and Clare Windsor for the extremely well-thought-out design of this booklet. But the biggest thanks go to Iain Fletcher, the driving force behind the project, who receives no credit at all in the booklet. Iain has been ably assisted by members of Surrey RIGS. Members of the London Branch of the OUGS have, in the past, helped with some of the conservation of the sites.

At £1.50 this booklet is a real snip and goes a long way to explaining the essential elements of Weald geology even if you don't want to walk the 5-mile trail. This cheap price reflects the contributions form SITA Environmental Trust and the John Daniels' Memorial Fund. The booklet is available from the Information Centre at Newland's Corner on Sundays, or through Surrey RIGS, the London Branch of the OUGS, or the BGS shop in the Natural History Museum.

The Official Guide to the Jurassic Coast: A Walk Through Time. Edited by Professor Denys Brunsden for the Jurassic Coast, Dorset and East Devon World Heritage Site and published by Coastal Publishing 2003. 65 pp, £4.95 (paperback) ISBN 0954484509.

The other guide is not so much a single geological trail as 'A Walk Through Time' along 95 miles of the Jurassic Coast, an area of 'outstanding universal value' that has succeeded in its bid for World Heritage Site status. This 65-page booklet is a condensed version of the earlier larger tome produced in support of the nomination. Not quite small enough for the pocket, but nevertheless this book is a useful accompaniment in the field. It has a pull-out map of the whole coastline at the back, with the geology clearly marked and thumbnail photos with explanations and access details for the main areas of interest. As with the Albury Trail, each location is supported by a double-page spread with stunning photographs of this superb coastline and the occasional diagram or wild-life image as required. This is truly a 'Walk through Time' starting at Exmouth with the spectacular red rocks of the Early Triassic and proceeding up the stratigraphical column through the Early Jurassic Liassic rocks at Lyme Regis with their famous fossils, on through the honey-coloured Middle Jurassic at West Bay and the Upper Jurassic of Portland and Lulworth Cove, beyond to the terrestrial Cretaceous around Swanage, and finishing with the dramatic Chalk stacks of Old Harry's Rocks at Studland.

This near complete Mesozoic succession of largely unspoilt coastline is the main raison d'être of World Heritage status. The title 'Jurassic Coast' is therefore something of a misnomer. Other factors include the continuing geological processes along the coast such as the massive landslipping at Bindon, the formation of Chesil Beach, and the processes in cove/bay development as seen at Stair Hole, Lulworth Cove and Mupe Bay.

The introduction outlines the implications of World Heritage status and goes on to show the geological sequence of events in the formation of the coastline in a clear and concise manner. It continues its introductory section with full-page spreads on each of the Triassic, Jurassic and Cretaceous, giving modern analogues, examples of fossils, palaeogeographies and reconstructions. Finally, in the introduction, there are pages on 'Shaping the Coastline' and 'The Birth of Science', highlighting major figures whose studies on the Jurassic Coast contributed to our present knowledge.

This small book is well worth £4.95 and gives an excellent overview of the 'Jurassic Coast'. At the back it gives phone numbers for coastal visitor centres, museums and other useful contacts, including a link to Dorset RIGS and its own website: www.jurassiccoast.com. I would recommend a visit to get a flavour of the book and for supplementary information and animations of the diagrams demonstrating coastal processes. I hope that in the future the extended geological section, illustrated over 20 pages in the nomination book, will be published again with additional information for the more advanced geologists. Copies are available from the World Heritage Team Dorset CC, Natural History Museum and BGS shop within the museum.

Postscript. I teach geology to adult classes and have recommended both books as essential reading to back up my courses on the Weald and Dorset respectively.

Diana Clements

Igneous and Metamorphic Petrology by Myron G Best 2nd edition, 2003, Blackwell Science Ltd 729pp (paperback) £34.50 ISBN 1405105887.

I purchased the first edition of this book back in 1990, when I studied S339. It has been my key reference book on "hard rock" petrology ever since, so I was keen to review this second edition. By coincidence, I had recently completed a study of Best & Christiansen's "Igneous Petrology"(ref 1) and was amazed to find that the first thirteen chapters of Best (2003) were practically identical to Best & Christiansen's book! Although this made my task as a reviewer a little easier, I was somewhat miffed to find that, had I delayed my original purchase by a year or so, I could have obtained the six chapters on metamorphic rocks for an extra £5!

The first edition, published in1982, was predominantly a book of descriptive petrology. The new edition has retained some of this original material, but has been rewritten to focus more on the processes involved in metamorphism and on the origin and evolution of magmas.

The first chapters comprise an overview of fundamental concepts and present the basic principles of thermodynamics and kinetics. Building on this foundation, the next four chapters consider silicate melts and volatile fluids, crystal-melt equilibria in magmatic systems and the kinetics of diffusion and crystallisation. In all case the processes involved are linked closely to the composition and textures of the magmatic products generated: indeed, this linking of process and product is a strong feature of the whole book. The following three chapters consider the behaviour of larger bodies of magma during ascent, emplacement and/or eruption. The final three chapters on magmatic rocks consider the generation and differentiation of magmas and the interplay of these processes within the range of plate tectonic environments.

The first four chapters on metamorphic rocks consider the nature of metamorphism, petrography, metamorphic mineral reactions and metamorphic fabrics. The final chapter on metamorphism builds on these chapters to consider the different styles of metamorphism occurring at different types of plate-tectonic margins. The final chapter of the book considers Precambrian rock associations, providing an interesting contrast to the predominantly Phanerozoic examples used in the rest of the book.

The book has a detailed table of contents, a useful index and a detailed glossary. Each chapter starts by listing the fundamental questions to be addressed in that chapter, thus promoting active reading. Each chapter ends with a set of review questions and a set of problems. Unfortunately, there are no answers given for the numerical questions.

This is a very well produced book, in a clear text with very few typographical errors. Diagrams and photographs are particularly clear. Although the book is a large paperback weighing 2.3kg, it is strongly bound and should withstand the frequent use that you will want to make of this excellent book.

Reference 1:

Best & Christiansen. "Igneous Petrology". Blackwell Science Ltd, 2000. ISBN 0-86542-541-8. Pbk £29.50.

Duncan Woodcock BSc Hons (Open), Continuing ES student

Geology and the landscape of Scotland by Con Gillen, 2003, Terra Publishing, 245pp, £19.95 (paperback) ISBN 19035440902.

Con Gillen, educated at and gaining degrees from the Universities of Glasgow, Aberdeen and the Open University has taught at the universities of Paisley, Glasgow, Dublin, Aberdeen and Edinburgh and has long been a tutor with the Open University. He has trained in the geology of the North West Highlands and is a member of the Glasgow, Edinburgh, Highland and London geological societies as well as the Irish Geological Association, and has Chartered Geologist status of the Geological Society. Much of his teaching has been devoted to introducing the geology of Scotland to those new to the subject. He is an accomplished linguist and has compiled a comprehensive Russian / English geological dictionary and has worked with Russian colleagues on the world's deepest research borehole in the Kola Peninsula, Arctic Russia.

A truly excellent book crammed full of information and beautiful photography which illustrates and explains the geology of the Scottish landscape from the ancient Lewisian in the far north west to the Ordovician and Silurian of the south east via the relatively young Tertiary of the Inner Hebrides and the sediments of the Devonian and Carboniferous. All the photography is reproduced in black and white, which is my one piece of negative criticism, since I and others who attended the OUGS Symposium in 1999 at Aberdeen have had the privilege of viewing the colour versions during Con's lecture there.

Initially the reader is given an overview of the rock fabric of Scotland and here we are told about the cause and effect of the various geological processes and how they relate to Scotland. Faulting, the rock cycle, folds and shear zone mechanics, and time and life are all covered to give the novice reader an insight and the tools to understand the story of how the varied and stunning scenery of Scotland evolved. We are then taken on a journey which began 3 billion years ago from the Lewisian of the Outer Hebrides, through the evolution of the Caledonian mountains to Ordovician post Iapetus growth of the Southern Uplands. The sedimentation and volcanism of the Devonian and Carboniferous in the Midland Valley are described and a really comprehensive picture of these times given.

The beauty of this book is that both the beginner and the expert will find it a good read due to the author's talent for keeping things simple yet informative. Students will find it a good reference guide for both the major events and the chronology of the evolution of Scottish rock.

The chapter covering the Tertiary is especially interesting and the volcanic nature of the major Islands from Arran to Jura and Skye is well illustrated – St Kilda even gets a mention. Other topics covered include the effects of glaciation on landforms and the economic resources provided by Scotland's minerals and oil. Finally a nice touch is a piece tracing the effects we humans have had on the landscape over the centuries.

Stuart Fairley, BSc

The Earth: A Very Short Introduction by Martin Redfern, 2003, Oxford University Press, 141pp, £6.99 (paperback) ISBN 0192803077.

I enjoyed this little book, jam-packed with easy to read facts about the home planet. It is a small book, and there were obviously limitations on the space available. The author recognises the difficulty of his task - as he says, 'How can you put a big round planet in a small flat book?' He has chosen to take the top-down approach, viewing the Earth as a whole, with descriptions of the processes that created it and continue to change it.

There are several useful diagrams. However, it is hard to visualise some of the processes that have been described only in words. For example, it is so much easier to take in the stages of the rock cycle with a simple diagram. I do feel that more illustrations would have been useful, particularly at the beginning. He gives the clearest explanation of ring dykes and caldera I have ever read, maybe because there is not overwhelming detail. I also appreciated the concise description of the eruption of mount St Helens. There are mind-boggling facts, such as the rate at which iron is crystallising in the iron core, 800 tonnes a second, and that the oldest imprints of raindrops date from 3 billion years ago, in India.

I found some parts difficult to understand. For example on page 94, he refers to Venus having tectonics without the plates. Now I can cope with plate tectonics, but I thought the whole idea of tectonics is that the plates are shuffling around. There is no glossary in the book, and with no Earth Sciences Dictionary readily to hand, (if that would help), I'm still confused.

Despite its limitations, I can thoroughly recommend this book as a reasonably priced pocket sized overview of geology. It is one of a series of Very Short Introductions published by Oxford. Number 100 in the series is Evolution -I will look out for it.

Sue Russell, BSc Hons (Open) and Primary School teacher